R & D ACTIVITIES: CONSIDERATIONS OF A STRATEGY FOR CANADA

by

Pierre Lamontagne

Thesis presented to the Department of Economics, Faculty of Social Sciences of the University of Ottawa, as partial fulfilment for the degree of Master of Arts

Ottawa - Canada - July, 1971

TABLE OF CONTENTS

LIST OF TABLES

LIST OF CHARTS

FOREWORD

The object of this thesis is to study science and technology or, more precisely, the Canadian research and development (R & D) effort, its intensity, its distribution and its features in order to appraise or, if possible, to improve the formulation and implementation of Canada's strategy in this field. National scientific resources both in financial and human terms, are necessarily limited and they pose a special problem of rational allocation if they are to bring to the nation the maximum benefits with the minimum costs. Thus, this study, involves both scientific and policy considerations.

In its policy aspect, this thesis deals essentially with an economic problem, namely that of the optimum allocation of scarce resources. But its scientific analysis properly belongs to what is now called the science of science or scienomics. This new science studies scientific activities in an attempt to explain their behaviour in much the same way as economics accounts for economic activities through a body of empirically verifiable laws.

The limited theoretical analysis and the heavy reliance on foreign sources of material can be explained by two reasons. First, scienomics has not yet been able to build an impressive body of sophisticated knowledge. Only since the late 1950's has the literature on the subject been increasing rapidly. But in spite of these fast improvements, the theoretical stage of that science has not yet been reached.

Second, Canada has lagged behind most advanced countries, in the creation of centres devoted to various aspects of the science of science. Therefore, when Canadian studies were not available, it has been necessary to assume that conclusions of certain foreign investigations applied as well to Canada. That assumption, as will be seen later, is not unrealistic.

This study would have been impossible without the patient advice and the numerous suggestions contributed by Dr. O.J. Firestone. For this most valuable assistance, the author wishes to express here his deepest gratitude.

CHAPTER I

INTRODUCTION

Scientific and technological knowledge has not been increasing at the same rate and affecting man in the same manner throughout centuries. In fact, it is the rapidly rising rate of accumulation and application of knowledge since the Second World War which is responsible for the growing awareness and concern over the effects of science and technology. Economists, especially in the last decade, have attributed to this phenomenon an increasing importance as a factor of economic growth. For this and other reasons, governments have devoted more attention to the national R & D effort and have begun to elaborate strategies that could lead to a better allocation of scientific and technological resources in their respective countries.

This introduction is intended to describe briefly the history of science and technology, the relationship between them and economic growth, the international and national institutions created to study science activities, and finally to present an outline of the scope and nature of this thesis.

1. History of Science and Technology

Although science and technology have developed more rapidly in recent decades, their origins can be traced as far back as the emergence of the primates.[1] However, scientific and technological knowledge did not begin to be organized systematically in the West before the development of the Phenecian, Egyptian and Greek civilizations. The progress then made was later assimilated by the Roman Empire and marked the origin of many sciences existing today. But even at the apogee of the Roman culture, philosophy, mathematics, astrology, medicine, chemistry and other disciplines were still often considered as arts rather than sciences. After the fall of the Roman Empire and up to the Renaissance, scientific and technological knowledge went through a period often referred to as "The Dark Ages". During the 15th and especially the 16th centuries, the great revival of art, literature and learning in Europe emerged and marked the transition from the medieval period to the modern era.

An important turning point in the history of science and technology came with the Industrial Revolution which developed in the latter part of the 18th century in England. Its impact was to change the social and economic

---

[1] Singer, C. Holmy and, E.S. and Hall, A.R. (editors), A History of Technology, Oxford University Press, Amen House, 5 volumes, London, 1954.

organization of society and was mainly characterized by the invention of James Watt's steam engine which, among other things, led to the beginning of large-scale industrial production. Technological progress continued at an accelerated rate during the 19th and 20th centuries and received a new impetus during the two World Wars. After 1945, R & D laboratories multiplied in industry, in universities and in the government sector throughout most advanced countries. This has since been described as the international scientific and technological race. The institutionalization of research and development activities became necessary for those nations wanting to keep pace with and add to the explosion of knowledge in order to benefit from its applications.

Today, the growth of international science and technology, has reached remarkable proportions. Professor Derek De Solla Price[2] has described this phenomenon by saying that science activity increases exponentially at a compound annual rate of roughly seven percent. At this rate, the effort devoted to science doubles every 10 to 15 years. R.A. Charpie[3] has estimated that the doubling time for the growth

---

[2]Price, D.J.D. Solla, "The Scientific Foundation of Science Policy", Nature, Volume 206, London, 1965, pp. 233-238.

[3]Charpie, R.A., "Technological Innovation and International Economy", Technological Innovation and the Economy, edited by Maurice Goldsmith; Science of Science Foundation, London, 1970.

of technological knowledge was approximately two to three years. Such an accumulation and application of scientific and technological knowledge have a deep influence on most aspects of society, especially its economic life.

2. Science, Technology on Economic Growth

Scientific and technological knowledge may be transformed into new methods of production, new designs for existing products, or for entirely new products and services. Research and development are activities which add to this knowledge and their results can be used to yield technological innovations, thus contributing to economic growth.

Although economists agree that these innovations are an important factor responsible for economic growth, they differ in their assessment of the magnitude of their contribution. Several surveys carried out in the 1950's concluded that about 90 percent of the long-term increase in output per capita in the United States was attributable to technological innovation, better education and other similar factors.[4] E. Denison, in a more recent study, estimated that the "advance of

---

[4] In particular, S. Fabricant, "Economic Progress and Economic Change", 34th Annual Report of the National Bureau of Economic Research, New York, 1954; R. Solow, "Technical Change and the Aggregate Production Function", Review of Economics and Statistics, August, 1957.

knowledge" contributed about 40 percent of the total increase in the national income per person employed between 1929 and 1957.[5]

Although these studies are helpful, they are not conclusive evidence. First, there exists complex interactions among the various factors affecting economic growth and it may be difficult to single out one of them such as technological innovation and measure exactly its own contribution. Second, this factor does not only have a positive effect on growth; it can also have a negative consequence by rendering existing technology obsolete and by destroying partly or completely old industries. Even if it were possible to isolate new technology from other factors, it would still be considerably difficult to measure exactly its net impact on growth. Third, the contribution of technological innovations to national economic growth is not the same in all countries. It may be considerable in a country like Japan which has limited natural resources and may be less significant in a country like Canada where the abundance of raw materials constitutes an important basis for growth. There is sufficient evidence to support the contention that the effects of new technology have become more important in recent

---

[5]Denison, E., The Sources of Economic Growth in the United States; Committee for Economic Development, 1962.

times and that they have produced considerable benefits and costs, both economic and social in all developed countries. Chapters V and VI deal with this aspect at greater length.

3. Study of Research and Development Activities

The growing realization that technological innovations were becoming an increasingly important factor of economic growth has led advanced countries to devote a rising portion of their resources to their national R & D effort and to try to draw the maximum benefits from them. Thus, science and technology emerged as a strategic subject of national breadth which became known as science policy.

In the early 1950's, the Organization for Economic Cooperation and Development urged member countries to try to develop their national science policies more systematically and they themselves endeavored to assist them in this attempt. This organization gradually expanded its interest in this topic and created in 1961 a Directorate for Scientific Affairs which is still headed by Dr. Alexander King. In 1963, the OECD held its first ministerial meeting on science policy. Since then, it has published a great number of reports and statistical surveys on R & D expenditures and manpower.

These publications can be divided into two categories. The first is a series of reports describing and appraising the national science policy of each member country. Eleven national reviews have been published, including one on Canada in 1969 and one on the Soviet Union which is not a member of the OECD. The second group deals with general topics related to science, technology and innovation, such as R & D in OECD Member Countries: Trends and Objectives; The Conditions for Success in Technological Innovation and Science, Growth and Society: A New Perspective.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) has also issued a great number of publications on science policy which could also be divided into two groups. Since 1965 UNESCO has published seventeen science policy studies and documents which deal either with particular countries or general science and technology topics. Their most recent and substantial study examines all European countries under five headings: Structures, Human Resources, Financial Resources, Operational Mechanisms of Science Policy and International Aspects.[6]

---

[6]United Nations Educational, Scientific and Cultural Organization; National Science Policies in Europe; Science policy studies and documents # 17, UNESCO, France, Paris, 1970.

In several countries, new institutions have been set up to study science, technology and innovation in an effort to better understand these activities and the technical and professional people engaged in them and to discover empirical laws explaining their features and behaviour. The United States are leading the way in this new field: the Federal Government, the National Academy of Sciences, look-out institutions, like the Hudson Institute, the Rand Corporation or the Stanford Research Institute and university centres, the most important of which are located at the Massachusetts Institute of Technology, including the Sloan School of Management, Harvard University with its Program on Technology and Society, Columbia University and Berkely. All these institutions have important research programs related to the science of science. In Europe, the best known university centre is the Science Policy Unit at the University of Sussex. It is not exaggerated to say that literature on scienomics is also now growing exponentially.

In Canada the first statistics on research and scientific activities covered the Federal Government expenditures from 1938 to 1946.[7] A more comprehensive and in depth examination of the national science effort was produced by the Glassco Commission in 1963.[8] Special studies were made

---

[7]Ministère de la Reconstruction et des approvisionnements, Les recherches et l'activité scientifique, dépenses fédérales du Canada engagées de ce Chef, de 1938 à 1946, l'oeuvre de M.O.J. Firestone en collaboration avec Mlle R.E. Addison, Imprimeur du Roi, Ottawa, 1947.

[8]The Royal Commission on Government Organization, Queen's Printer, Ottawa, 1963.

by the Science Secretariat created in 1964 and by the Science Council established in 1966. A more elaborate national inquiry was undertaken by the Senate Special Committee on Science Policy which has published more than 10,000 pages of evidence since 1968[9] and the first volume of its report in 1970.[10] The university sector has been practically inactive in this area, as shown by the briefs presented by some 40 Canadian Universities to the Senate Committee.[11]

Interest in the national science effort is recent and limited in Canada, as compared with major industrialized countries. This gap should be filled as the importance of science and technology is rapidly growing in the world. Canadians should attach greater attention to this aspect of their national life if they wish to continue to grow and become an innovative society.

4. Scope, Method and Plan of this Thesis

This thesis analyzes Canada's present R & D effort, in the light of the international technological race. It consists of two parts. The first six chapters review the research and development activities in Canada, their major, actual and potential effects on the economy and society in general, and

---

[9] *Proceedings* of the Special Committee on Science Policy; the Senate, Queen's Printer, Ottawa, 1967 to 1969.

[10] Report of the Senate Special Committee on Science Policy; *A Science Policy for Canada*, Volume I, Queen's Printer, Ottawa, 1970.

[11] *Idem*, pp. 193-214.

the factors contributing to their performance. This part also serves as a background for the last two chapters. These offer suggestions for the improvement of Canada's strategy in the fields of science, technology and innovation. This second part is based primarily on the characteristics of basic research, applied research and development and on the different mentalities of the two main types of professional workers engaged in these activities.

This approach is being followed because it can be shown that contrary to suggestions often made, it is impractical to develop a proper strategy by merely establishing national objectives. This latter method implicitly assumes that R & D programs can be determined without knowing the nature, the character and the specific objectives of these activities. Some important national goals may require little research to be met, others may be achieved simply by importing the results of research already done abroad. It is obvious, therefore, that the importance of national goals cannot determine, at first, the priorities and the strategy of a country's science effort. It is only once the specific features and objectives of the various R & D activities have been carefully considered that it becomes possible to organize them so as to meet national requirements more effectively.

Finally, two appendices complete the thesis. The first one includes the tabular material referred to in the different chapters while the last appendix involves the enumeration of all books, articles and other readings which were necessary for the elaboration of this thesis.

CHAPTER II

FRAMEWORK OF ANALYSIS

This chapter is concerned with the establishment of a foundation necessary for the examination of R & D activities. It deals with the definition of these activities, and their linkage to other variables. This framework of analysis sets the tone of the present paper and puts in perspective the chapters that follow.

1. Definition of R & D Activities

Research and development activities may be defined by using two different approaches. One method consists of identifying and enumerating the activities that fall into the R & D category and those that are excluded from it. Although this has the advantage of being clear and precise, the fact that the enumeration is, for practical reasons, endless, presents a definite drawback. This method is used by the Dominion Bureau of Statistics and by the National Science Foundation. The following definition of research and development was used in the 1967 D.B.S. survey.

a) Scientific R & D is investigative work carried out:

   1) to acquire new knowledge,

   2) to derive and develop new products or processes,

3) or to apply newly acquired knowledge in making technically significant improvements to existing products or processes. When necessary to test a new or improved product or process, the design, construction and evaluation of a pilot plant or prototype are included in scientific R & D.

b) For the purposes of this survey, scientific R & D does NOT include:

1) market research and sales promotion,
2) research in the social or psychological sciences,
3) operations research, except when required during the development phase of a product or process,
4) quality control or routine testing of products and materials,
5) geological and geophysical surveys, mapping, exploration and similar activities not resulting in scientific or technological advance,
6) all activities necessary for commercial production of the new or improved product or process.

c) Development ceases and production begins when the work is no longer experimental. Hence, the costs of the preparation of specifications and other engineering information for the construction or operation of facilities for production and the costs of production tooling cannot be attributed to R & D. Similarly, a pilot plant, once the original investigative work is over, may be used as a production unit. Its operating costs may then no longer be considered development costs.

d) A research unit may spend a portion of its time on routine testing of materials and products or on "trouble-shooting". The effort devoted to such activities is not research or development.[1]

---

[1]D.B.S., Industrial R & D Expenditures in Canada, 1967, Queen's Printer, Ottawa, 1969; pp. 1 and 2.

The second method distinguishes between the type or nature of the activity involved in research and development: basic research, applied research and development. This approach provides a broader point of view and pretends to describe three different stages of the R & D process. It also implies a static and categoric distinction in the delineation of the stages. Most authors carefully remind the reader of these theoretical disadvantages. The Science Council of Canada uses the latter mode of defining research and development, but restricts itself only to the three categories.[2] More and more, writers want to distinguish between types of basic research and even between types of applied research. These sub-categories help to explain, in greater detail, the nature and goals of R & D activities.

In the United Kingdom, the Zuckerman Committee of 1961 put forward the most complete set of definitions as follows:

> We have taken "research and development" to mean, in general terms, all those activities which are directed towards the acquisition of scientific facts and techniques, or towards their application, to the design of new or improved materials, or equipment, or to the devising of new processes, often involving, in the later stages, the construction of prototype equipment or pilot plant.
>
> We have found it helpful to differentiate between five categories of activity normally included under the portmanteau term, research and development. These are pure basic research, objective

---

[2]Science Council of Canada, Towards a National Science Policy, Report No. 4, Queen's Printer, Ottawa, 1968, p. 7.

basic research, applied (project) research, applied (operational) research, and development. Our definitions of these terms are set out in the following paragraphs. We would, however, emphasize two points. First, there is and can be no clear-cut line of demarcation between one form of research and another; basic research and development are, so to speak, bands at opposite ends of a continuous spectrum. Second, most organizations engaged in research will be concerned to some extent with the whole range of research and development.

(i) Pure Basic Research

Pure basic research is research carried out solely in order to increase scientific knowledge: that is, knowledge of the nature of the material world. Such research is commonly called either "fundamental" or "pure" or "basic". These words, particularly "fundamental", are often connected with the idea of work of high intellectual quality. A fair amount of "pure" scientific research may, however, be of a routine or of a preliminary nature. For example: (i) "filling in", where a main breakthrough has already been made; (ii) exploratory work in fields where a good deal of semi-empirical experimentation is needed before the real problems can be identified; (iii) descriptive observational work, notably in biology and geology. A line of "pure basic" research is selected by the individual worker to satisfy his own tastes and intellectual curiosity.

Examples of pure basic research are:

A study of the properties of high energy cosmic ray particles. The correlation of the chemical and structural changes that take place in muscle during its contraction and relaxation.

(ii) Objective Basic Research

Between "pure" and "applied" research there lies an intermediate category of scientific work to which we have given the name "objective basic". This denotes basic research in fields of recognized potential technological importance. It is well known that the pursuit of defined technological objectives, for example the development of a supersonic aircraft, sometimes exposes an area in which existing scientific knowledge is seriously insufficient. It then becomes necessary to try to organize an increase in this knowledge before a further technological advance can be made. Research of this type may be as intellectually exacting as what we have called "pure basic" research. The difference between "pure basic" and "objective basic" research derives mainly from the fact that the latter is stimulated primarily by technological needs. It therefore calls for a planned approach even when the satisfaction of these needs is remote. This characteristic of "relevance" to a definable technological objective is a practical criterion which differentiates "objective" basic research from "pure basic" research.

Examples of objective basic research are:

The study of the fundamentals of plasma physics, which may provide data likely to be of value to work on thermonuclear fusion directed to the harnessing of new sources of energy. A study of the growth of virus in living cells, which may provide information of value in combating virus infections of man.

(iii) & (iv) Applied (Project or Operational) Research

As indicated above, applied research has as its object the attaining of a practical goal, which can be fairly precisely defined, such as a new process or piece of equipment. We believe that this type of work is best described as project research to distinguish it from applied research directed to improving the use of an existing process or piece of equipment. The latter may be called operational research.

Examples of applied research are:

Project. To provide design data for a nuclear-powered submarine. To determine the cause of the specific failure of a particular crop and to derive a remedy to prevent its recurrence.

Operational. To improve the working performance of an existing type of graphite-mode carbon dioxide-cooled nuclear reactor. To provide the data for improving the design and layout of farm buildings by a study of their purpose and day-to-day use.

(v) Development

Development bridges the gap between research and production. It may be defined as the work necessary to take, for example, a new process or piece of equipment to the production stage. It will often include the erection and operation of pilot plants or the construction of prototypes.

Examples of development are:

The work required to determine the best production techniques for a nuclear reactor, research having determined the necessary composition of the fuel elements and the materials for the containers. The work required to determine the appropriate process for manufacturing penicillin on a large scale, research having established its antibiotic properties, and small-scale trials its clinical usefulness.[3]

One could suggest other classifications of research activities by distinguishing "programmatic research" which is research conducted by using a written time plan from "non-programmatic research" which is not scheduled. Or one could differentiate between non-oriented research, pre-product oriented research and product oriented research which covers approximately the same approach as the second method referred to above. But enough has been said to indicate the importance of having a clear understanding, a priori, of what concepts are being used. In this thesis, the second method is used and

---

[3]Report of the Committee on the Management and Control of Research and Development; Office of the Minister of Science, HMSO, London, 1961, pp. 6-8.

R & D activities will include those operations in science and engineering ranging from a generalized search for new knowledge to the construction of prototypes and pilot-plants. As to definitions of the different types of research, those of the Zuckerman Committee are adopted.

Two other concepts need clarification in any discussion of R & D activities: Science and Technology. Although these terms are often used side by side, the latter is quite distinct from the other in nature and in goals. These distinctions and the links existing between science and technology are examined in Chapters VII and VIII. Here it is sufficient to define them.

The first concept is described by the Science Council of Canada as meaning:

> Man's accumulated and systematically arranged knowledge about himself and his world and the research by which he continually adds to this body of knowledge.[4]

Other definitions exclude the activity of research; however, as a whole, they attribute to it a similar meaning. In this thesis "science" is that body of accumulated knowledge which tries to explain rationally and systematically, human and natural phenomena by formulating empirical laws accounting for their behaviour. Science is the result of scientific research while scientific advance represents an addition to that

---

[4]Science Council of Canada, Towards a National Science Policy for Canada, op. cit., p. 7.

body of knowledge. It is distinguished from technological advance in that the former is directed towards understanding while the latter is towards use.

Technology refers either to a state of affairs as of a point of time or to changes over time. The former entails a static concept and the latter a dynamic one in which case the term "technological change" is used. *

Technology according to Mansfield is defined in these terms:

> Technology is society's pool of ... knowledge regarding the industrial arts. It consists of knowledge regarding (1) the principles of physical and social phenomena, (2) the application of these principles to production, (3) the day-to-day operations of production.[5]

The term "technological change" involves a movement through time. Nelson defines it as follows:

> Technological advance is an increase in knowledge relevant to economic activity ... advances in knowledge which when put to work result in an increase or improvement in output ... (it), in a broader sense, also includes improved management techniques and new concepts for organizing economic activity.[6]

Mansfield's definition bears a close resemblance to that given above:

---

[5]Mansfield, Edwin, The Economics of Technological Change, W.W. Norton & Co. Inc., New York, 1968, p. 10.

[6]Nelson, R.R., Peck, M.J., Kalachek, E., Technology, Economic Growth and Public Policy, The Brookings Institution, Washington, D.C., 1967, p. 22.

* Technical change can consist in the alteration of the character of the equipment, products and organization which are actually being used.

> Technological change (says Mansfield), is the advance of technology such advance often taking the form of (1) new methods of producing existing products, (2) new designs which enable the production of products with important new characteristics (includes new products), (3) and new techniques of organization, marketing and management.[7]

Both definitions imply an advance, increase or improvement in output. The perspective of this concept is broadened by Solow when he says:

> Using the phrase "technical change" as a shorthand expression for <u>any kind of shift</u> in the production function. Thus slowdowns, speedups, improvements in the education of the labor force, and all sorts of things will appear as "technical change".[8]

Unlike the two previous authors, Solow speaks not only of a positive "technical change" but also implies the existence of a negative one for certain periods.

Other distinctions are made in the literature of technological change. One involves the differentiation between capital-saving, labor-saving and neutral technological change. When change results in a greater percentage reduction in capital inputs than labor inputs, it is capital-saving. When the reverse is true it is labor-saving; and when the percentage reduction between both inputs is equal, the result is called a neutral technological change. The other distinction relates to capital-embodied or disembodied technological change. The latter refers

---

[7] Mansfield, Edwin, op. cit., p. 10-11.

[8] Solow, R., "Technical Change and the Aggregate Production Function", <u>Review of Economics and Statistics</u>, August 1957.

to technological changes, consisting of better methods and organization that improve the efficiency of both old capital and new. The former being changes in technology that must be incorporated in new equipment if they are to be utilized.

In this thesis the definition of technological change is that given by Mansfield and Nelson presented in its broadest sense. That is, that technological change is an advance in applied knowledge resulting in an increase in, or improvement of the production function, such as maximizing the output rate from given amounts of inputs. This definition includes changes in techniques of organization and management.

Technological change, advance, innovation, and improvement will be used in reference to the definition given above. Technological innovation occurs when new knowledge is applied for commercial activity, i.e., marketing a new or improved product or process for the first time.

Out of all these definitions, one aspect is particularly noteworthy. They all exclude explicitely or implicitely, research and innovations in the social and psychological sciences. In the past the study of these sciences has been neglected to the point where even today no extensive records exist of the amount of research carried on in these fields. The systematic organization of research in social sciences will be needed to study the behavior and solve the problems of the technological society.

2. Linkage With Other Strategic Variables

When Joseph Schumpeter examined the economic application of science to industry, he established a decisive difference between invention and innovation. On the one hand, invention represents the creation of a new idea or a new technique. On the other hand, innovation consists of the application of that new idea or technique to the production process. But the path between an invention (or idea) and the market place is a hazardous and complex venture, replete with obstacles and substantial risks. It is ordinarily a costly, time-consuming and difficult task facing the innovator.

Research activities carry out the first step of that process. Inside laboratories, new ideas are discovered, scientific leads are followed up and basic inventions eventually emerge to the surface. This first stage is followed by a series of other stages, necessary to create a new product or service and to market it. Technical and economic uncertainties are reduced to an acceptable risk; engineering is charged with designing the product, tooling and machinery, while market probes study the demand, and the potential profitability of the new (improved) product or process. Once manufacturing and marketing start-ups commence, the prudent entrepreneur has removed most obstacles with eventual success resting on adequate sales expansion.

But most projects hardly ever reach the stages beyond research and development. Mansfield among others, explains:

> One of the most obvious and important characteristics of research and development is the uncertainty of the outcome ... Chance plays a crucial role, and a long string of failures must often be sustained before any sort of success is achieved. For example, a recent survey of 120 large companies doing a substantial amount of research and development projects indicated that in half of these firms at least 60 percent of the R & D projects never resulted in a commercially used product or process ... Moreover, even when a project resulted in a product or process that was used commercially the profitability of its use was likely to be quite unpredictable.[9]

The high risks involved in R & D activities tend to limit the amount of time and money going to a particular project. Let it be assumed (a) that success is quite eminent and (b) that technical and economic uncertainties have been satisfactorily dealt with; in that case, two prime factors have to be considered: time and costs.

Once a new invention has been created, a number of other steps have to be taken to convert it into an innovation. This time period varies substantially since some inventions require more or less important changes in tastes, technology, and prices. Time is an important factor in the innovation process. Lead time over competitors may represent the difference between a profitable innovation and a loss.

---

[9]Mansfield, Edwin, Industrial Research and Technological Innovation, W.W. Norton & Co. Inc., New York, 1968, p.16.

Restricting attention to more important inventions, the data given by John Enos provide some feel for the distribution of the time lag.[10] He estimates the time interval to be eleven years for eleven important petroleum refining processes and fourteen years for thirty-five important products and processes in other industries. Their respective standard deviations were five and sixteen years. Other similar studies have shown that the lag has been decreasing over the years.[11]

The second factor considers the cost of innovation. The typical distribution of costs in successful product innovations has been calculated by a panel for the U.S. Secretary of Commerce (see Chart I on page 205).

The cost distribution presented here is also used by the OECD and indicates that research and development activities take up less than 10% of all costs attributed to innovative efforts. The major portion is devoted to getting ready for manufacturing.

The fact that R & D activities are the first stage of innovation and that they are relatively inexpensive permits the entrepreneur to make an early estimate of risks and uncertainties without having to spend considerable amounts of money

---

[10] Enos, J., "Invention and Innovation in the Petroleum Refining Industry", The Rate and Direction of Inventive Activity, Princetown, N.J., 1962.

[11] In particular F. Lynn, "An Investigation of the Rate of Development and Diffusion of Technology in our Modern Industrial Society", Report of the National Commission on Technology, Automation and Economic Progress, Washington, D.C.: 1966.

to discover that the potential innovation is not possible or profitable. Therefore, more can be expended on the first stage and if it is successful, other steps towards innovation can be pursued.

Ultimately, innovations are imitated or adapted by individuals other than the originators. This last step is called the diffusion process. Consumers, firms or other countries may discover, through time, the profitability of certain innovations and decide to emulate them. Here again there is usually a time lag which depends on the rate of diffusion. For the twelve industrial innovations studied by Mansfield,[12] the average time between first use and use by 50 percent of the ultimate users was twelve years; ten more years elapsed before 90 percent of the ultimate acceptance was reached. In the first case the time interval varied from nine to fifteen years.

The rate of diffusion of a new producer good is determined by its ultimate profitability. Furthermore, if only a small financial commitment is required to adopt an innovation, if there is relatively little uncertainty regarding its performance and if the initial risk decreases at a rapid rate, then diffusion is made faster. In the case of consumer goods, the key role of diffusion rests on the tastes, and preferences of consumers as well as on promotional means and

---

[12]Mansfield, E., Industrial Research and Technological Innovation, op. cit., p. 142.

the rate of consumer assimilation. Presumably, the more rapid spread of innovations nowadays is mainly due to improved communication channels, and more sophisticated methods of profitability assessments.

Therefore, technological innovations may go through these stages. Research and development can be represented as only one link in the chain of possible events but its importance lies in the fact that its results entail a linkage with other strategic variables. Therefore, three main steps can be isolated from each other: the invention, innovation and diffusion processes, each depending on the success of its predecessor. The following chapters deal mainly with the first two steps.

CHAPTER III

OPERATIONS OF R & D ACTIVITIES

This chapter examines the operation, extent and distribution of R & D activities in Canada in recent years. These activities, various in nature and scope, have been funded and performed by both private and public sectors of the economy, the former sector being represented by industry and the latter by governments, universities and other non-profit organizations. The analysis covers (1) the total R & D effort in Canada, (2) its distribution in the economic system, (3) its most important agents and finally (4) an international comparison.

1. Total R & D Effort

This section is concerned with two aspects of Canadian R & D activities: total expenditures and employment.

Total Expenditures

In 1956, the Dominion Bureau of Statistics first published, in cooperation with the National Research Council, an estimate of the magnitude and direction of the research-development program undertaken by Canadian industry in 1955. Four years later, in 1960, DBS again with NRC, was publishing for the first time a report on Federal Government Expenditures on Scientific Activities for the fiscal years 1958-59 and

1959-60. These two publications have been compiled biennially up to 1967, at which point the latter catalogue became annual. Although a definite effort has been made in refining concepts and extending detailed data publication, as yet, the Bureau has made only small attempts to publish aggregate figures for the whole country and has not provided continuous and comparable year-to-year series. Nonetheless, total expenditures of R & D in Canada can be obtained from other sources: the Science Council and the Organisation for Economic Co-operation and Development.

In 1967, total expenditures of R & D in Canada were $895.5 million or 1.4% of the GNP in current dollars.(Table I). In eleven years, the Canadian research effort has almost tripled while the country's gross national product has doubled. This takes no account of price changes. The problem of adjusting GERD to changes in prices is that there is no price deflator available for those particular expenditures. Due to the lack of a better method, the implicit price deflator for GNE, based on 1961, is used in Table 2 to adjust R & D expenditures in constant dollars. This crude measurement permits the expression of GERD in real terms.* It first reveals a more accurate picture of the actual R & D Canadian effort and second it allows year-to-year growth rates to be calculated without price prejudices. Annual percent increases in GNP and GERD figures indicate no significant corrolation

*A more accurate measurement of GERD in constant dollars could be arrived at by deflating independently capital and wage expenditures by sector of performance. The latter expenditures could also be deflated by category of personnel.

between both series. The performance of the nation's economy did not directly affect the spending pattern of Canadian R & D organizations. Other factors explain more substantially the variations in GERD growth rates. Chapter VI elaborates further. Finally, average growth rates over the ten year period, show that R & D expenditures in Canada have increased twice as fast as GNP.

Manpower in R & D

Another way of measuring the extent of R & D activities in Canada is in terms of the number of people engaged in such activities. Regrettably, employment data are more limited than expenditure figures, such statistics being available only for three years, 1963, 1965 and 1967 (see Table 3).

These figures reveal another side of the character of Canadian scientific research and indicate the relative importance of R & D manpower to total employment.

Table 3, first distinguishes between three categories of R & D personnel but does not provide separate statistics for scientists and for engineers. DBS does not yet publish this data for these two professions. However, the categories above give some picture of the structure of Canadian R & D activities and the relative importance this country attributes to them in the performance of scientific operations. Technicians represented 35.7 percent of the total research and development personnel while both scientists and engineers accounted for 37.2 percent in 1967. The latter figure is relatively high if the qualifications required for these professions is taken into due consideration. These three manpower categories differ in academic competence but their percentage importance does not necessarily reflect the strength of the educational system. In fact, Frank Kelly estimated that in 1969 professional and technical workers formed the largest single segment of workers entering Canada, whereas one thousand scientists and engineers emigrated each year, primarily to the United States.[1]

Second, annual totals do not include all of the scientific and technical population. Some who are qualified in these areas perform administrative or managerial jobs which constitute employment outside formal R & D activities. However, total figures for R & D staff show an absolute increase over the four years, as well as proportionately to total national employment.

2. Distribution of R & D Activities

Research and development activities are performed and funded by business enterprises, governments, universities and private non-profit organizations. This section examines the share of these institutions in Canada's total R & D effort.

---

[1]Kelly, F., Prospects for Scientists and Engineers in Canada, Background Study for the Science Council of Canada, Special Study No. 20, March, 1971, p. 18.

Table 4 sets out the sources of funds channelled into Canadian R & D operations.

Sources of R & D Funds

The data indicate that all sectors have increased their contribution in 1967, by at least twice as much as in 1957. This increase has been continuous throughout the eleven years except for government and industry between 1957 and 1960. These years were marked by slow growth and even some decreases in R & D expenditures. This low in R & D activities was primarily due to the cancellation of the Arrow program in 1957. Another noticeable aspect is the difference in the rates of growth between sectors. Private non-profit organizations and especially universities have enjoyed faster growth rates than government or industry. On the one hand, the former sectors have increased their share of funding activities by 10.0 percent over the years, with a 1967 contribution of 15.5 percent. On the other hand, governments, although they have doubled their R & D expenditures during the eleven year period under review, have reduced their percentage share by 15.0 percent, advancing 53.4 percent of national funds in 1967. Industry's total contribution has varied between 24.1 and 33.5 percent annually. Over the years, it has been relatively steady so that no definite trends can be established. Therefore on a short-term basis, industry's share has changed inversely to that of the government's. In the long-run, however, the gap opened by the government sector has almost completely been filled by universities and other organizations. This shift in the sources of R & D funds in Canada has been in great part attributable to government policy changes who favoured universities as a more propitious location for basic research.

Performance of R & D Activities

Another aspect in the distribution of R & D activities to be noted is the performance of the various sectors. The main point is that the amount of research carried on by a sector is not necessarily related to its funding share. Table 5 presents a statistical breakdown by performance sector.

All sectors have increased their R & D performance by at least fifty percent between 1957 and 1967. Industry has been the largest performer of R & D activities followed closely by government; in fact, government was the most important performance sector between 1959 and 1963. Since then, the latter reduced its share while industry and "others" did not develop any definite trend.

On the one hand, the university sector has shown a substantial increase both absolutely and relatively to its share of performance. This behaviour coincides with its increasing share in funding R & D activities. On the other hand, government has also followed the same policy in its performance and funding activities; however, contrary to the university sector, it has contributed steadily smaller shares over the years in both cases. A comparison of the data in

Tables 4 and 5 indicates that both government and other sectors spent more dollars to fund R & D than they did to perform it, while the inverse was true for industry and universities. The net flow of funds was channelled from the former to the latter sectors.

Research and Development Manpower

Yet another way of measuring the sharing of the total Canadian R & D effort is by analysing the distribution of research and development personnel. Data availability limits the comparison to five years and to biennial figures only (1963-1967). Total R & D manpower in Table 6 is divided by sources of funds between performance sectors. Business enterprises include government enterprises, co-operative industrial research institutes and associations; general government consists of the federal and provincial governments with their research councils and foundations. The private non-profit sector is made up of organizations such as charitable foundations and voluntary health agencies. Higher education contains such institutions as universities and colleges.

General government was, for 1965 and 1967, the employer hiring the largest number of persons engaged in R & D, replacing the business sector which placed first in 1963. Higher education and private non-profit organizations remained third for the whole period. Nevertheless, they almost tripled their scientific staff, somewhat to the detriment of industries. In 1963, fifty percent of all scientists and engineers were engaged in business enterprises; in 1967, their number had decreased by 12%. Over this period, higher education and non-profit organizations had gained 11% of the total number of scientists and engineers.

A similar situation existed for the second category of researchers called technicians. From 1963 to 1967, the business sector reduced their count by 9%, and the university sector increased it by 8%. General government kept its share fairly steady in all three categories and it continuously employed more men in the third category, that of supporting personnel. In fact, over 50% of government R & D personnel fell into that category.

The distribution of manpower between sectors bears close resemblance to that of expenditures. In both sets of data, strength lay in government and industry; over the years these sectors lost some of their original standing to private non-profit organizations and especially to universities; the difference between both series of figures is that shifts in expenditures moved from government while shifts in manpower moved from industry.

Types of R & D Activities

Still another aspect of the distribution of the total R & D pie is concerned with the types of activities. Among others, the Dominion Bureau of Statistics distinguishes between basic research, applied research and development. These terms have been defined and analysed in the previous chapter. All sectors conduct the three types of research and the data in Table 7 show that each sector is characterized by a predominance of one or the other.

In 1965, the bulk of Canadian R & D expenditures was spent on applied research and development (77.6%). Nevertheless, fundamental research represented almost a quarter of R & D activities at that time. Approximately the same picture can be drawn for 1967. The Senate Committee on Science Policy reports that the percentage distribution of total R & D expenditures by type of activity in that year was 38.9 for development, 38.0 for applied research and 23.1 for fundamental research.[2] It will be shown later, in an international comparison, that Canada is one of the few countries which devotes a relatively large effort towards fundamental research.

The distribution of these activities between sectors of performance, shows a definite delineation of functions. Industry dedicated 68.4% of its effort to development, government and non-profit organizations 64.0% to applied research

[2]Report of the Senate Special Committee on Science Policy: A Science Policy for Canada, Volume I, Queen's Printer, Ottawa, 1970; p. 125.

and higher education devoted 70.0% towards fundamental research. Not only did each sector perform a high percentage of a particular type of activity, but they also represented the greatest source of that type of activity. Industry carried out 81.9% of all development, government 56.2% of applied research and 60.0% of all fundamental research was performed by higher education. According to these statistics, government is the least concentrated sector and applied research is the type of activity most widely performed by all sectors. The inverse is true for the two remaining sectors; development is to industry what fundamental research is to higher education.

Foreign R & D Effort

The last aspect of this second section will be concerned with the foreign R & D effort in Canada as compared to the domestic one. Table 8 depicts the situation for 1963-67. The statistics therein cover all funds used in Canadian R & D which come from outside Canada and are designated as R & D funds. These figures do not include funds spent in Canada by foreign-owned industries, institutions and organizations.

Foreign sources of funds for R & D are not particularly important in Canada; for the period under study they ranged between 2.8% and 5.3% of the total funds. This small proportion was distributed between the three sectors of which business enterprises and higher education were the main recipients.

3. R & D Activities Within Sectors

This section examines R & D activities within each sector: industry, government, universities and others.

a) Industry

Different kinds of R & D expenditures can be distinguished. Intramural expenditures are differentiated from extramural in that the latter constitutes a payment for R & D performed by other firms and organizations for the reporting company. A distinction is also made between current and capital expenditures. The latter includes such costs as land, buildings and equipment.* R & D industrial expenditures can be separated between those carried on domestically and those outside of Canada. Table 9 brings out these distinctions and establishes their relative importance.

Total Industrial R & D Expenditures

The increase in the number of reporting companies has not been due solely to the growing number of firms engaging in R & D activities but also to the scope of the DBS survey whose coverage was expanded from year to year. To distinguish between the two, the Bureau reports in tabular form on the number of R & D establishments, by year of foundation. In 1967 and early 1968, 49 of these establishments

---

*Current expenditures include approximately 80% wages and 20% of minor equipment.

were founded out of 849 which reported; this represents 8% of the total number of R & D firms established since 1867.[3]

Total industrial R & D expenditures increased at a continuous rate except for 1959-61; this decline can be explained by a decrease of expenditures in the transportation equipment industry from $67.3 to $19.9 millions. The cessation in 1957 of the Arrow aircraft development program was the main cause.

As Table 9 shows, the majority of Canadian industrial R & D expenditures were performed intra-murally. Although capital expenditures represented only a small percentage relatively to current expenditures, the former increased its share over the last ten years by about 4%.

Research and development activities funded by Canadian industries but performed extra-murally, were mostly undertaken outside the country. In fact, for the period 1957 to 1967, the proportion of foreign to total extra-mural expenditures in industry varied between 80.8% and 94.5%. This high percentage of foreign extra-mural expenditures is in great part attributed to the transfer by foreign-owned subsidiaries of their R & D activities to their headquarters in the mother country.

---

[3]Dominion Bureau of Statistics: Industrial Research and Development Expenditures in Canada, 1967, The Queen's Printer, Ottawa, 1970; p. 52.

Industrial R & D Concentration

To illustrate the distribution and concentration of R & D expenditures among the different industries, intra-mural outlays are most commonly used. Two sets of time series are available: the first covers the years 1959 to 1964 and are found in the 1963 DBS catalogue. The second time series on intra-mural expenditures begins in 1963 and is available up to 1968. Regrettably the two series are not fully comparable due to different industry classifications. Only the latter set is reproduced in Table 10.

Manufacturing firms performed the bulk of R & D activities and the great majority of industries conducting them fall into that category. As a matter of fact, that sector of the Canadian economy has spent between 86.7% and 94.4% of total intra-mural R & D expenditures. Within manufacturing, spending has been concentrated in a few industries. In 1961, the five largest industries shared 70% of a $114.0 million while in 1968 the same industries shared 64.5% of all intra-mural expenditures. Supplementary data are presented in Table 11 on the greatest R & D spenders.

Three industries, electrical products, aircraft and chemical products, have been responsible for over 50% of current R & D expenditures; the first industry has constantly increased its share, whereas the aircraft industry decreased it. Including the next three largest industries, the pecrcentage goes up to 75%. The petroleum products industry which was the sixth largest spender in 1963 was in fourth place in 1968. As for other industries, figures show a percentage increase from 1964 which may indicate a widening as opposed to a concentration of R & D expenditures.

Industrial Sources of Funds

Examination now turns to the sources of funds. Is industrial R & D activity heavily subsidized by government, or is it mostly auto-financed? To what industries do most government funds go? Data elucidating these questions are presented in Tables 12 and 13.

Since 1957, government has decreased its share in the funding of industrial R & D activities. Auto-financing was as high as 77% of all sources of funds in 1967 and combined with government, the percentage climbed to 91%. The two largest spenders of R & D funds were also those industries receiving the largest amount of federal support. The government in 1967 allocated over 75% of its R & D expenditures to the electrical product and the aircraft and parts industries.

Table 13 does not include funds received by companies under the Industrial Research and Development Incentives Acts (IRDIA). This assistance from the Government of Canada was highest for the following industries in 1965: electrical products, $8.9 million; petroleum products, $7.8 million; chemical products, \$7.0 million; paper, \$6.4 million; and primary metals, \$4.4 million. All five are among the six largest industries engaged in R & D and the sum total of the IRDIA allotted to them amounted to over 80% of these federal grants. IRDIA grants are paid for R & D performed in the past and do not necessarily indicate the current level of R & D. Nevertheless, they are an important source of funds concentrated in a few industries.

Industrial R & D Manpower

The distribution and concentration of R & D manpower among industries is yet another aspect which confirms the above findings (see Table 14).

Once again, the largest R & D performers employed the largest number of scientific personnel. The first five industries possessed 70% of the total R & D manpower and total manufacturing, 93%. All industries except electrical products had over 50% of their manpower in the supporting personnel category, the majority of which were technicians. The electrical product industry had the highest number of scientists and engineers followed by the chemical products and aircraft industries; all three employed 54% of QSE's, i.e., qualified scientists and engineers. Furthermore, 74% of QSE's in 1967 held bachelor degrees while the percentage for both masters and doctoral degrees were 26% for all industries. These statistics may indicate one of three things: that there is a shortage of master and doctoral degrees in science and engineering, or that industry simply prefers to invest in personnel endowed with a limited theoretical background in order to train them thereafter. The third possibility is that QSE's are somewhat reluctant to work for industry and that those with higher academic degrees have more opportunities for work outside that sector. Frank Kelly's study almost eliminates the first possibility.[4] Therefore a mixture of the other two is more probable.

b) Government Sector

The OECD in Reviews of National Science Policy: Canada, points out the preponderant position of the Federal Government in Canadian science activity:

> The outstanding feature of the organization of scientific activities in Canada is the prominent part played by the federal government ... Since the end of the Second World War it has directed research more systematically towards solving the problems connected with the country's specific resources and the training of university, scientific and technical staff ... These preoccupations are reflected in the present structure of the federal agencies and centres of investigation; in addition to institutions devoted to research there are a number of ministerial departments responsible for studying renewable resources, non-renewable resources and collective needs.[5]

---

[4]Kelly, F., Prospects for Scientists and Engineers in Canada, op. cit., p. 8.

[5]OECD, Review of National Science Policy: Canada, Paris, 1969, p. 87.

The analysis of the government sector covers two levels: the federal and the provincial. Both levels are approached in a fashion similar to that of industry. The distribution and concentration of government R & D expenditures and manpower are examined on a departmental or agency basis.

Total Federal Expenditures on Scientific Activities

The Federal Government spent $568 million on scientific activities in the fiscal year 1967-68, of which $386 million or 68% for research and development. The remaining 32% was divided as follows: scientific data collection 11%, scientific information 4%, testing and standardization 3%, scholarships 2% and capital expenditures 12%. The topic of this paper is concerned with that part which deals with R & D activities. Table 15 gives the distribution of these federal expenditures by sector of performance.

Generally, two main trends appear over the period under review. The Federal Government first decreased its share of performance by 13.0% between 1963 and 1968 and second, allocated more funds to universities and non-profit institutions. Still, government laboratories performed over fifty percent intra-murally. More particularly the bulk of extra-mural government expenditures went to industry and universities. On the one hand, federal contracts and grants to industry for research and development amounted to $84.2 million for 1967-68, of which $53.7 million or 60% was funded by the Department of Industry. Including $19.3 million budgeted for IRDIA grants, R & D expenditures of that Department to industry amounted to 96% of total R & D expenditures. Of all the work performed by industry for the Federal Government, 75% fell under industrial assistance programs while the remainder were contract programs.

On the other hand, Canadian educational and non-profit institutions received $71.7 million from the Federal Government in 1967-68; the National Research Council contributed 53% while the Medical Research Council allotted 25% of all funds granted to those institutions.[6] The 1967-68 current expenditures for these two agencies amounted to $88.1 and $18.7 million respectively. Of these funds, 43% for the NRC and 99% for the MRC went to these educational and non-profit institutions. The remaining extra-mural federal expenditures (4%) were attributed to provincial governments and foreign recipients. Intra-mural outlays of the Federal Government remain to be examined. Table 16 distributes these R & D funds among departments and agencies but MRC and the Department of Industry do not appear since they did not perform intra-mural R & D activities.

---

[6]Dominion Bureau of Statistics, Federal Government Expenditures on Scientific Activities for the Fiscal Year 1967-68, Queen's Printer, Ottawa, 1970, p. 34.

Distribution of Federal Intra-Mural Expenditures on R & D

Total current intra-mural government expenditures on research and development has increased from $146.0 million for the fiscal year 1963-64 to $237.0 million for 1967-68.

In 1958-59, the four federal departments or agencies, National Defence, Agriculture, Atonomic Energy of Canada and the National Research Council performed 82.6% of all intra-mural R & D, while in 1967-68, the percentage decreased to 74.5%. The difference in concentration was mainly due to the Department of Energy, Mines and Resources which, in that year, spent 10.6% of these federal funds, bringing the percentage for the first five departments or agencies up to 83.1%. Furthermore, over the years the departments of Agriculture and National Defence have decreased their percentage of performance while the AEC and NRC have increased it.

Federal R & D Expenditures by Type and Area of Application

The next aspect refers to the kind and the extent of research and development activities that the Federal Government performed. Two thirds of the departments and agencies engaged in all three categories: basic research, applied research and development. Table 17 depicts the most important performers.

Most departments and agencies performed more applied research than any of the other two categories of R & D. The exceptions are the NRC, which devoted almost 50% of its funds to fundamental research and National Defence which spent 40% on development. The most important areas of application of these federal expenditures were, for 1967-68, (1) military science, funded at a rate of 63% by the National Defence Department, (2) agriculture, fishing and forestry, half supported by the Agriculture Department, and (3) nuclear science for which 99% is carried on by AEC.

Federal R & D Manpower

The four largest spenders are also the four largest employers of R & D personnel: Atomic Energy of Canada Limited, the Department of Agriculture, National Defence and NRC respectively (see Table 18). The same is true for total supporting personnel. The differences occur in the type of researchers and in their qualifications. While National Defence had the highest number of technicians, the Department of Agriculture employed the greatest number of scientists and engineers. On the one hand, the latter department and NRC possessed the largest number of employees with high academic standings. On the other hand, AEC, EMR and National Defence employed a high percentage of their scientists and engineers with bachelor or master degrees. These differences in academic background could be attributed to the predominance of certain types of research, certain fields of research or certain areas of application in which these departments or agencies are engaged.

Provincial R & D Activities

Other government bodies in Canada are also engaged in R & D activities, namely provincial research councils and foundations. They were established to assist industries in their respective province with technical problems and to aid the development of provincial natural resources. Six provinces had, in 1967, research councils or foundations: British Columbia, Alberta, Saskatchewan, Ontario, New Brunswick and Nova Scotia. Two other provinces, Quebec and Manitoba, had the intention of establishing such organizations. Total expenditures for 1967 amounted to $14.5 million, only 1.5% of the aggregate national R & D expenditures (see Table 19). Nevertheless, total R & D expenditures for provincial research councils and foundations more than doubled between 1963 and 1968. This increase was invariably due to intra-mural expenditures.

The principal sources of funds were the Provincial Governments (64%), Canadian industry (16%) and the Federal Government (14%). Ontario, Alberta, and Nova Scotia had the largest number of provincial research councils or foundations and their respective research foundations also had the largest capital programs. Chemistry, earth sciences and metallurgy were the major fields of science towards which these funds were directed; they accounted for 63% of current intra-mural expenditures. Finally, the provincial research councils and foundations estimated that most of their R & D "should be considered applied research (72%) with the remainder evenly divided between basic research and development."[7]

The comparison of R & D outlays between the two levels of government indicates that the federal's contribution is without doubt the most important one. However, provincial governments proportionately devote more resources to industrial applied research and as their jurisdiction is increased (medical sciences for example), their contribution may also grow. The Federal Government would keep supporting those aspects which are considered of national breadth and importance.

c) Universities and Private Non-Profit Organizations

Universities and non-profit organizations place third and fourth among the sectors of the economy engaged in R & D activities. The analysis of the operations of research and development in these institutions involves the brief study of the sources of funds, their areas of application and their R & D manpower characteristics.

---

[7]Dominion Bureau of Statistics, Industrial Research and Development Expenditures in Canada: 1967, Queen's Printer, Ottawa, 1970.

University R & D Expenditures

The growth of university research in Canada in recent years has been experiencing a period of such rapid expansion that observers have called it an "explosion" of research in Canadian institutions of higher learning. Statistics for the last several years are not available as yet. The OECD in their 1969 review of the Canadian science policy used the 1964-65 figures of the National Research Council survey. Table 20 indicates the rapid development of university funds spent for research between 1955-56 and 1964-65.

In the ten-year period, university research funds have doubled every three years, although funds for operating and minor equipment have decreased proportionately to total expenditures. The greatest percentage change from year to year was registered in 1964-65. When data becomes available for subsequent years they are likely to show similar growth rates, especially for 1967 when the Federal Government increased markedly its research contribution program to universities.

Canadian universities fund a great part of their own research. According to estimates by the NRC for 1964-65, these institutions carried over fifty percent of the load. Table 21 gives a more detailed account of the major sources of funds for university R & D.

Non-university contributions amounted to 40% of which the Federal Government's share was 26.8%; the NRC and the Medical Research Council distributed nearly 80% of the federal total.

The number of research programs carried on by Canadian universities was concentrated mainly in five disciplines: in order of magnitude, engineering, biological sciences, agriculture, chemistry and physics or geophysics.

The total number of personnel engaged in research activities for 1964-65 reached 10,960. Candidates for higher degrees ranked first with 6,010, faculty members near 3,000, technicians and supporting staff numbered a little over 1,600 and post-doctorate fellows were last with only 320 doing research work.

R & D Expenditures of Non-Profit Organizations

Non-profit organizations are the smallest performers of R & D activities in Canada. DBS has published only a brief paper on their scientific activities in 1965. Expenditures for these Canadian organizations, for that year, were estimated at almost $15 million. Of this total, over $12 million was for scientific research and development. This amounts to 1.7% of all Canadian R & D expenditures. Non-profit organizations are divided into five groups: private foundations, hospitals, scientific and technical societies, semi-provincial government organizations and voluntary health organizations. The sources of funds of these organizations are shown in Table 22.

On the one hand, hospitals and voluntary health organizations were the largest recipients; they received respectively 44% and 35% of funds. On the other hand, private individuals were the most important single source followed by the Federal Government and provincial governments. Industry and foreign sources were estimated to have provided 1.3 million to non-profit organizations in 1965.

Hospitals and semi-provincial government organizations were the main performers of R & D and other groups were mainly collectors and distributors of funds. The application of funds for scientific research and development were primarily attributed to intra-mural expenditures in hospitals while extra-mural R & D went in great part to educational institutions and other hospitals. The field of health registered the largest number of scientists and engineers for 1965. In fact, the proportion of physicians and surgeons to others was almost as high as 60%. Lastly an estimated 423 full-time supporting personnel were accounted for, of which slightly over 50% were considered to be technicians.[8]

International Comparison

The operations of R & D activities in Canada have been described in the last three sections by comparing the relative importance of each sector and their agents. But

[8] Dominion Bureau of Statistics, Expenditures on Scientific Activities by Non-Profit Organizations, 1965, Queen's Printer, Ottawa, 1970, pp. 2 and 3.

how is a country to know if her total scientific effort is both adequate and efficient, or if certain sectors are devoting too little or too much of their funds and manpower towards certain types of research and development? International comparison provides one of the means for appraising the national effort. The following section proposes to study this aspect in general, by using OECD tables and by grouping them into four parts: total expenditures and total manpower, funds, performance and type of research activity.

a) Total Expenditures and R & D Manpower

According to Table 23, Canada plays only a small role in the realm of R & D activities. In fact among the ten selected OECD countries, she ranked ninth in 1963 while she held the eighth position with Sweden in 1967. Seven countries, in the four-year interval, increased the proportion of their R & D expenditures to GNP, by an average of .28%. While Canada registered a positive change slightly over that average, U.S.A. and Belgium declined by .1%.

The United States led all countries in 1963 and 1967 as the greatest spender of dollars on R & D both in absolute and relative terms. In fact Americans in 1967 accounted for 67% of all R & D expenditures done in the ten OECD countries. This situation has made policy leaders of Canada ask themselves serious questions as to the future of their technological and economic position and prestige. The

United States also led all countries in R & D manpower, employing in 1967 over half a million qualified scientists and engineers (QSE's), equivalent to 58.6% of the total number in the ten countries. Canada's share of that manpower was only 2.1% and she ranked sixth among nations. If the number of QSE's in R & D is taken as a percentage of the total civilian labour force, Canada advances to third position with a ratio of 0.26. The proportion for U.S.A. is three times that of Canada and leads all countries.

b) Type of Research Activities

The second aspect of this international comparison presents the distribution of national R & D expenditures between the amount spent on fundamental research, applied research and development, with relevant data summarized in Table 24.

Table 24 is arranged so that countries performing the highest percentage of development are first in rank. Canada placed seventh just before Belgium, and second in both other types of research. Judging by the figures above, Canada has spread her effort fairly evenly among the three research categories, whereas most other countries have concentrated their funds away from fundamental research and towards development.

c) Performance of R & D Activities

Yet another aspect where Canada shows the same even balance of shares is in her distribution of R & D expenditures by sector of performance (see Table 25).

On the one hand, Canada placed last among the ten OECD countries in the amount performed by the business sector; a difference of over 16.0% with the closest runner-up, France. On the other hand, the same country ranked first in the percentage share of government R & D performance and held the same position, with Germany, in the other two sectors. In most other countries, R & D activities were performed predominantly in the business enterprise sector at a rate of over fifty percent of the total national scientific effort. The high concentration of government R & D performance in Canada has led the Senate Special Committee on Science Policy to conclude that this situation may have been one of the major errors of this country's scientific programs. In fact, the Committee pointed to the inadequate communication between government laboratories and the commercial sector. Many inventions due to this weak link never reach the stage of innovation, says the Senate Committee.

> Empirical evidence shows that the ideal location for R & D activities is where their results can be used, that is, where the innovation can be developed and introduced. This location, in an economic system mainly based on private initiative, is in industry. On that basis, at least what most other advanced countries are doing seems to be right and Canada appears to be on the wrong track.[9]

---

[9]Report of the Senate Special Committee on Science Policy, A Science Policy for Canada, Volume I, Queen's Printer, Ottawa, 1970, p. 128.

d) Funds for R & D Activities

Finally, an international comparison is made on the distribution of national R & D expenditures by sources of funds.

In Table 26, countries are ranked in order of their percentage contribution of R & D funds to business enterprises. Canada placed tenth in 1967 according to that ranking arrangement with a difference of 47% compared to Switzerland. American industry carried only a third of the burden while the government sector contributed the second largest amount among all the OECD countries. Canada, in the latter sector, followed the United States with slightly over fifty percent of total national funds. However, if government R & D expenditures are taken as a percentage of all government expenditures, Canada registered the lowest ratio of the six largest countries since 1959. In 1967, the percentage figure amounted to only 2.3 for this country while the first place, U.S.A., had a 5.7 ratio. Canada's deficient scientific effort can therefore be largely blamed on the Federal Government and on the industrial sector whose weakness is often attributed to extensive foreign ownership. The Senate Committee on Science Policy for Canada concludes prudently:

> But the Committee is certainly justified in concluding - on the basis of comparisons with other advanced countries - that the Canadian situation is strange and that Canada's de facto science policy is unique, to say the least.[10]

Although the Canadian situation may appear strange and unique, it would be premature to conclude from that alone that it is not justifiable. This chapter has tried to depict Canadian R & D operations as they were <u>in fact</u>; the two last chapters of this paper consider Canada's special position and offers suggestions as to what her future R & D strategy should be <u>in theory</u>. Before attempting to present these considerations, the economic effects and causes of R & D activities are examined in the following three chapters.

---

[10] Report of the Senate Special Committee on Science Policy: <u>op. cit.</u>, p. 22.

CHAPTER IV

ECONOMIC EFFECTS OF R & D ACTIVITIES

Commencing with the 1960's, economists have increasingly acknowledged the importance of research and development activities as a significant factor in the growth process of both industry and the economy as a whole. This recognition led to a number of studies which identified "technological innovation" as a major factor determining the pattern and extent of these activities. In fact, general concensus has attributed to technology the dual functions of cause and effect of R & D activities. The effects are discussed in the present and following chapter, while causality is dealt with in Chapter VI.

The distinction, made earlier, between invention and innovation explained that the latter is the successful application of the former, and that between them there lies a series of steps necessary for the new or improved product or process to appear on the market. This transition from invention to innovation is not always technically possible or economically feasible. However, R & D activities have the potential economic effect of being transformed into technological innovations; when they are not, the effect is economically insignificant and may even represent a loss; when they are, the effects may either be positive or negative.

Technological innovation has been one of the important determinants of the North American economy.

> Technological change has improved working conditions, permitted the reduction of working hours, provided an increase flow of products, old and new, and added many new dimensions to our way of life ... Production facilities are automated, educational processes are aided by machines, space vehicles are developed, diseases are conquered, and countless other kinds of changes are made.[1]

The application of new knowledge has proven to be particularly beneficial for the industrial sector. The pending advantages of technological innovation have been a strong inducement for the promotion of science and technology. However, these activities have sometimes been pursued to a point where secondary effects have been neglected in favor of profitable returns. Today, the more somber side has effectively reached the masses. E. Mansfield brings out this aspect.

> Advances in military technology have made possible the destruction of mankind on an unprecedented scale, modern technology has resulted in air and water pollution, the closing of plants made obsolete by technological change has thrown whole communities into distress and the technological revolution in agriculture has contributed to serious problems both urban and rural.[2]

Technological innovation is a double edged sword; it can be carried out for its positive economic effects but it may also bring negative repercussions. The social scientist has to

---

[1]Mansfield, E., The Economics of Technological Change, W.W. Norton & Co. Inc., New York, 1968, p. 3.

[2]Idem, p. 3.

balance both the utility and disutility of any type of economic activity; the remainder of this chapter is devoted to the positive side of this balance while the following chapter deals with the negative aspect. An attempt is also made to attribute the different economic effects to those which are most affected: whether they be individuals, industries or society as a whole.

A. Positive Economic Effects

Technological innovation has contributed to the improvements in the standard of living, to the expansion of production capacity and to a wider range of choice of goods and services. It has raised and broadened the quality of human capital, reduced the number of working hours and increased the amount of leisure time.

The main influence of technological innovation on economic growth is its effect on productivity - the ratio of output to input. However, advances in technology are not the only determinants of the rate of growth of labor productivity. This rate is also affected by increases in the amount of capital per worker, increases in the extent of productive capacity, economies of scale and diffusion of best practices. Nevertheless economists agree that technological innovation plays a major part in the growth of output per manhour and that it can benefit wage earners as well as businessmen.

Industry

Most innovations are the product of the industrial sector; it performs the greatest proportion of R & D activities and is the logical agent for the introduction of most technological innovations. Industries conduct research activities primarily because the returns on this kind of investment offer various and potentially high rewards. Furthermore, the risk of failure can be reduced to a minimum with the help of recent sophisticated information services. R & D activities are not a new phenomenon in industry but the reductions of their uncertainties has lately made them more attractive, and therefore, more widely undertaken. Their èmergence in the industrial complex has somewhat changed the strategy of business enterprises, although their main economic role has remained essentially the same, namely that of producing and selling a given output utilizing the most profitable combination of inputs.

The growth of R & D activities in industry occurred due to a pressing need to increase the quantity and quality and to reduce the price of both inputs and outputs. Special emphasis was given to the development of new resources to meet the demands of both old and new products. Most new factors of production and the majority of innovations were drawn from the fields of electricity, chemistry, physics and mechanics. This recourse to scientific activities in industry has not altered the profit motive of business enterprises. Nonetheless, the emergence and development of industrial R & D activities in advanced countries have changed the structure of the economic system and brought about certain positive effects. Regrettably, the benefits reaped by one individual or group are often the seeds leading to technological costs for others. This interrelationship between economic effects reveals itself to be intricate in the present and following chapters.

Technological innovation may give rise to productivity gains, cost reductions or expansion of demand. These changes often entail greater profits which can be reinvested in R & D activities. But apart from financial rewards, business enterprises which introduce technological innovations eventually increase their power structure. The lead time of innovating firms gives them the opportunity to control input and product markets. On the one hand, productivity increases permit them to fulfill certain demands of trade unions, and automation offers a tool for bargaining power. On the other hand, product improvements attract new custumers and reduce competition forces so as to give more power to those individual concerns responsible for the innovation.

Thus, repeated R & D successes in one firm may tend to eliminate those performing little or no research in the industry and concentrate the power in only a few hands. This may bring about the emergence of what J.K. Galbraith calls the "technostructure".[3] Although this effect may be accompanied by such problems as size and organization, these big companies prefer the benefits of certain monopolistic powers which arise with the growth of large corporations. Furthermore, apart from being funded at a high rate by the Government, certain firms receive large Federal contracts and special assistance. They may also possess advantages when the market for their product is the Federal Government. This procedure is common in the U.S.A., especially in military releated work, but less frequent in Canada.

Research and development activities also carry other potential economic effects for industry. The discovery or improvement of certain processes or products may help to reduce production and distribution costs and enable firms to cope with changes in relative input prices. Expected increases in demand can be met with remedy proposals by company research laboratories and thus prevent potential competitive adversaries from entering the industry to satisfy excess demand.

Industrial R & D laboratories provide an added feature, namely the security aspect. They permit possible technological shifts from one product to another, answering a latent demand. The patenting of a new product or process by a firm provides yet another means of protection against potential imitators. Moreover, R & D activities help the business strategist

---

[3] Galbraith, J.K., The New Industrial State, A Signet Book published by The New American Library, New York, 1967.

in the swapping of patented inventions and in their licensing. This security strategy has partly contributed to the overwhelming number of unused registered patents.

Another economic effect, beneficial to the industrial sector, could be designated as cooperation linkage. This expression can be explained in the following manner.

At times a firm or industry which either does or does not undertake R & D activities, may face a new invention that has originated from outside its own laboratory or even its industry. For instance, the chemical industry has made several discoveries later adopted by the textile industry, a low R & D performer. Synthetic fibers is an example. The general case being that certain industries supplying raw materials to other industries discover products or processes which are found to be useful to their buyer. The reverse is also true, although less probable, i.e., the uncovering by a buying industry of new knowledge which offers potential applications to their supplyers. This exchange of technological innovations between industries benefits both sides in that it may reduce costs and improve relations between the industries involved in an exchange of knowledge.

Performing successful R & D activities may strengthen the competitive position of a firm both in domestic and foreign markets. On the one hand, many industries in their own country face American technological rivals. In order to survive or surpass them, domestic firms must engage in substantial inventive activities. A high rate of technological innovation in an industry acts like a tarif barrier against the invasion of foreign business enterprises. Canada, due to its U.S. proximity is especially striving to reach a higher level of innovative capacity. On the other hand, firms and industries, carrying on intensive research operations, stand a greater chance of extending their activities to external markets. Access to those markets may be achieved by keeping one step ahead of foreign technology.

Another positive economic effect is the reduction of the brain drain. The extension of R & D activities by industry and other sectors gives scientists and engineers employment opportunities at home. Further incentives such as sophisticated, up-to-date laboratory equipment, adequate salaries, and just treatment help to retain them in the firm, in the industry or in the country. Here, industry's interest is two-fold.

First, a large R & D manpower gives industrialists the advantages of a wide choice of researchers and the opportunity of obtaining the best scientists and engineers in their field. An adequate supply of specialized personnel also reduces the high costs of domestic or foreign competition in bidding for particular skills. Second, firms are interested in retaining certain scientists and engineers in which they have invested large amounts of capital to train and equip them. Furthermore, satisfaction develops their loyalty and reduces security leaks which may occur when frustrated scientists leave the firm.

All told, the performance and successful application of R & D findings can have on industry the positive economic effects of increased profit, power and security. Through this activity, business enterprises protect themselves against the possible emergence of technological obsolescence; this, in turn, encourages them to introduce new or improved products and processes.

Society as a Whole and Individuals

Society and individuals also benefit from R & D activities carried on by industry, governments, universities and other organizations. First of all, the performance of these activities provides work and income for scientists, engineers, technicians and supporting personnel. Consequently, further employment and income is created throughout the remaining steps of the process leading to technological innovation. This is directly attributable to research operations. It affects individuals related to them but also has repercussions on the consumption, employment and income patterns of society. No serious attempts have been made to estimate the "technological" multiplier effect due to obvious problems of measurement. However, among others, Prof. J.B. Quin of Dartmouth College contends that innovation may have the highest multiplier effect on economic growth.

A second positive economic effect on society and its members has been the reduction of the irksomeness of labor. Man has developed mechanical devices to eliminate tiresome and tedious physical work. He has used scientific and technological knowledge to reduce repetitions and routine tasks. This process has ultimately led to industrial automation and has given man a greater possibility to do more meaningful work.

A third economic effect, related to the previous one, consists of productivity gains. Automation has increased production capacities to fulfil society's needs, and improved human efficiency in work in order to produce goods in shorter periods of time, with fewer men, greater precision and even lower costs.

Computor technology is the latest example. It increases the speed of the learning process and the quantity and quality of information manipulation. It facilitates the task of decision making while at the same time raising the degree of reliability. Computer technology makes possible the handling of certain operations which were time-consuming or impossible a few years ago and added accuracy of results through the use of complex systems. Finally, it offers a new method of information storage and retrieval which is both time and space saving. The advantages of this system have proven to be especially useful to business enterprises, governments and universities in giving better and faster services to consumers and researchers across the country.

Productivity gains have resulted in higher income levels and in shorter working hours. With the reduction of the working day to eight hours man can now enjoy more leisure and spend more time on discretionary pursuits.

Technological innovations have also helped greatly in raising society's standard of living by the introduction of and accessibility to new and improved products. New forms of energy, transportation and communication systems have given to the consumers the comforts of heating, lighting and electrical appliances, the benefits of speedy and extensive travelling and the opportunities of cultural and educational entertainment. Home electrical and mechanical devices as well as chemical products have considerably reduced the time devoted to house work and thus has permitted housewives to get an education and enter the labor force. The subsequent effect has been both economic and social. Faster and better means of transportation have resulted in the reduction of time to and from the job and has extended the space in which individuals can operate. Furthermore it has caused an increase in tourist activities and has widened people's horizons. New communication systems have also been time saving. They have eliminated some travelling and increased the speed of transmitting information. Moreover, the extension of this information, virtually to all levels of society, has raised the educational standards of the majority.

A fourth effect of technological innovations on individuals and society has been the reduction of sickness and disease as well as the prolongation of the life span. The improvement of health has diminished losses of income and production due to injuries and sickness. Advanced health technology has permitted both the prevention and cure of certain diseases which previously brought disability and premature death. With the help of electronic devices, incurables have been rehabilitated and given back at least part of their usefulness in society. Not only has research resulted in innovations capable of remitting health but it has also led to increasing life expectancy. Although such advances benefit the individual, they also present population problems for some societies.

The performance of research and development activities are profitable to society as a whole in that they promote the increasing utilization of resources with minimum waste. It is in the interest of both industry and society to use resources to their maximum potential. Once they are restricted in supply, their value increases and a price must be paid for their scarcity. R & D operations often result in the discovery or improvement of new products and processes which increase input productivity and even replace certain expensive factors of production. These gains can be favorable to society and are sometimes passed down to consumers in the form of reduced prices. This economic effect can also be seen in cases where wastes are transformed into marketable by-products.

R & D activities in preventing the brain-drain do not only benefit industry but also society as a whole. When scientists and engineers leave the country in which they have received their professional training, a loss is incurred. First, resources and capital investments which were spent for their university education are lost to the nation's competitors which draw on their scientific output. Second, the potential discoveries which these scientists and engineers are capable of providing, are given up with the economic benefits that society and its members could have inherited. Therefore research operations help to retain the services of those engaged in their execution and give to society its due return on investment.*

Other economic benefits can occur to society through the actions of the imitator. The imitator is that person who applies someone else's idea in an unaltered or insignificantly altered form. He may borrow the innovation, carry out a small amount of research on it and come up with an improvement in the quality or in the price of the product. He does not have to

---

*Positive economic effects of R & D activities described above warrent more explanatory development than mention here. However, elucidating on these effects would imply a more profound study which could be postponed to another paper.

face the large initial investment of R & D and by slightly altering the innovation the imitator can profit by it. Apart from personal rewards, the imitator provides society as a whole with certain benefits. He increases competition which contributes to price decreases and induces qualitative changes in the product. He further enlarges the choice of the consumer by widening the variety of product differenciations. In the process of extending the market, he creates employment and income and urges the innovator to innovate once more. The adaptor also affects the economic system similarly to the imitator but outside the innovating industry. He modifies knowledge, developed elsewhere, to his own circumstances using essentially the same body of knowledge.

Transposed internationally, the imitator becomes part of what is called the product cycle theory. Above all, Japan is the typical country personifying the imitator. This theory holds the contention that an innovating country exporting its technological advances, reaches a point where the amount of the new product imported by the imitating country reaches a peak. The latter country then introduces a cheaper or improved form of the product and, after having conquered its own domestic markets, proceeds to export it. Thereafter, a reversal of position develops where the originating exporter becomes the importer of the product which the imitating country then developed and sold. Japan often exploited the U.S., German and Swiss innovations and has been successful in many instances (see Chart II, p. 206).

Many authors debate the question of whether or not pure basic research has any economic effects on industry or on society as a whole. The majority of opinions tend to attribute to it an indirect economic significance; there have been some instances where fundamental research has contributed directly and in a short period of time to technological innovations, but these cases are isolated. Generally, this type of research aims at understanding the principles of the universe, and not at applying them to useful purposes. However, fundamental research is the basis without which technological innovations could not be perpetuated indefinitely. The economic effects of that type of research have not been studied in detail due to their intricate relationships over long periods of time. Nevertheless, basic research may have a greater future role to play especially in advanced countries where disadvantageous technological effects could be overcome by understanding the basic nature and principles of both physical and psychological fields.

The performance of R & D activities, in the past, have resulted in improving the quality of life and advancing the boundaries of knowledge. However, today, the positive economic effects of these activities are increasingly accompanied by negative economic effects which have been unknown or neglected. The following chapter deals with this aspect of R & D activities, bringing out the main costs of technological innovation.

CHAPTER V

ECONOMIC EFFECTS OF R & D ACTIVITIES: CONTINUED

More recently, the literature on R & D activities has expressed growing concern over the harmful effects of technological innovations on society and individuals. These criticisms can be summarized by four main reasons: (1) the lack of control over technological innovations, (2) the neglect to prevent and admit their damaging repercussions, (3) the necessity to acknowledge their extent and their sources, and (4) the need to reduce or eliminate the injurious effects that technological change may have on life and on the environment.

Research and development activities do not entail, intrinsically, any direct harmful effects; nonetheless, the application of their results, technological innovation, may bring about some unfavourable consequences, some of which may be foreseen and others not. This possibility counsels the social scientist to establish the negative effects that may flow from R & D activities. This subject is examined in this chapter under the headings: pollution, unemployment, waste, consumer sovereignty, alienation and scarcity of time.

Pollution

A major cost of technological advance is air, water, earth and noise pollution. Being environmental, it is one of the more visible and recognized consequences of technology.

Air pollution, especially in large cities like New York, Los Angeles and even Montreal, has risen to maximum acceptable levels. Vehicle exhaust pipes, gaseous industrial waste, atomic energy experiments and pesticides are the major sources of air pollution. Ecologists estimate that if the production of carbon monoxide keeps increasing at the present rate, the earth's atmosphere may become so saturated as to cause major changes.

There are two schools of thought regarding the high density of carbon monoxide in the earth's orbit. One sustains the melting of the polar caps due to the inability of the earth's heat to escape its surface. The other predicts a second ice age due to the inability of solar heat to reach the earth's surface. In either case, a crisis may arise. What is more important today is the effect of air pollution on human, animal and plant life. Pesticides, especially DDT, are known to be harmful to all types of life. Studies have reported the injurious effect of incesticides consumed with food, throughout the whole ecological cycle of animal and plant life. In fact, certain amounts of foods have been banned from the market due to unacceptable DDT contents. Moreover, air pollution threatens the reproduction of certain plant and animal species, thus breaking the necessary balance of nature. It has even been said to cause damage to the human body itself.

Ronald G. Ridker, on the basis of laboratory studies, has tried to measure the economic costs of diseases caused by or accentuated by air pollution.[1] His results, he admits himself, are not conclusive but he maintains that although his methods are limited by certain assumptions, the experiment is quite revealing. For instance, he makes the assumption that air pollution creates or increases man's vulnerability to (1) cancer of the respiratory system, (2) chronic bronchitis, (3) acute bronchitis, (4) common cold, (5) pneumonia, (6) emphysema, (7) asthma. He then proceeds to calculate the economic costs of (a) premature death (loss of output and burial costs); (b) treatment, and (c) absenteeism. The costs of the seven diseases associated with air pollution yielded a total of over $1,989 million in 1958. Almost half of this amount represented a direct loss of output in that year.

Air pollution does not only affect the human, animal and plant food supply but it also saturates the air and causes serious damage to all living organisms. Finally, air pollution can have what A.C. Pigou called social costs: the dirty countrysides, buildings, houses, clothes. How much is spent to have these cleaned? Moreover, these side effects

---

[1]Ridker, R.G., The Economic Costs of Air Pollution, Frederick A. Praeger Publishers, New York, 1967.

of air pollution affect property value, says Ridker. After conducting a survey of the census data on property values between a polluted area and a non-polluted area, Ridker concluded that:

> To the extent that property-value losses can be attributed to air pollution, those losses will be indicated more clearly by translating them into dollar terms ... Thus the average loss incurred by home-owners in the affected area who sold their houses after 1962, was between $1,144 and $799.[2]

Water pollution represents a similar problem because drinking water is a necessary component in any living organism. The greatest harm arises from industrial and household dumping. Lukasiewicz points out some of the problems and eventual costs:

> Thermal water pollution resulting from power plant cooling requirements presents one of the most serious long-range water resource management problems. Altering the temperature of water disrupts the whole ecological cycle of animal and plant life ... Deep well disposal of industrial waste, practiced by oil companies and others, eventually lead to contamination of fresh water wells and streams and may be responsible for earth quakes.[3]

Lake Erie is a "dead" example of water pollution. Ecologists say that in fifty years, this lake has aged one million years, and that it is now considered a dead body of water. The principal river of Western Europe, the Rhine, famous for its scenery, is now polluted.

---

[2] Idem, p. 150.

[3] Lukasiewicz, J., Complexity and Saturation in an Environment of High Technology, paper presented at the 34th Annual Meeting, ASEE, SE Section, Miami, Florida, U.S.A., April 17th, 1969, p. 18.

> From Lake Constance to the Netherlands it has become a gigantic open sewer ... But consider also that acid rain falling on Sweden, allegedly as a result of air (or water) pollution. It damages Swedish forests.[4]

The oil tanker "Torrey Canyon" in March 1967 struck rocks in international waters near the southwest end tip of England. Thousands of tons of oil were swept on England's coasts killing seabirds and other animals. Similar incidents were repeated off the coasts of Nova Scotia and California.

Household wastes, especially phosperous in detergents, are deadly to marine life. Not only does it present a threat to a potential food supply, as does mercury, but it may also reduce the air supply. Scientists say that 60% of the oxygen in the air comes from marine life plants; water pollution kills these plants and reduces the amount of oxygen. Without this basic component, all animal life is endangered of extinction. With a growing population, it will be important to keep those life sources, water and air, fit for human consumption.

Military technology may prove to be the biggest cost. Millions of dollars are spent on R & D for new weapons, such as ABM systems and others. What price must be payed for peace and protection? Nuclear energy entails new risks, in its peaceful as well as its military use. While a nuclear power station may not pollute the air, it would generate a mass of

---

[4]Calder, N., <u>Technopolis</u>, MacGibbon & Kee Ltd., Bristol, 1969, pp. 181 and 182.

hot, highly radioactive wastes which have to be buried for hundreds of years, at great expense. Fuel processing for nuclear stations unavoidably contaminates water with the same wastes. Atomic explosion and other testing on or in the earth have had unpredicted effects, and the risk of an accident to a reactor releasing radioactivity over large regions cannot be completely discounted.

Noise pollution is also a mounting problem, a technological cost that large communities must suffer. Airports and highways are often a source of daytime trauma and nighttime insomnia. A new gadget has been invented for sound sleep. In New York Times, February 8, 1969, an advertisement pictures a so-called "Pleasure Vac" with the following connotation: "A bargain in Acoustical Silence": $25.00 for the Deluxe model and $19.50 for the standard one. Moreover, how many sleeping pills and headache pills are on the market which proclaim relief? Lukasiewicz comments:

> Rather than analyse the causes of the detrimental effects of technology and institute remedies accordingly, we have often attempted to overcome the difficulties by, in effect, further augmentation of technology which has been responsible for them. Thus, freeways have served to increase the car population and aggravate transportation and other problems.[5]

---

[5] Lukasiewicz, J., op. cit., p. 31.

Pollution is by no means the only example of society's lack of control over technology. Many products have reached the consumer only to discover afterwards their dangerous aspects. The automobile's lack of safety represents a case in point. Many people, communities, even governments have applied pressure on car producers to increase safety features. But action has only been taken recently and minor improvements have been incorporated. Artificial sweeteners (cyclomates) provide another case. The possible effects of the new sweeteners were known only after a few years. Government laws were necessary and losses incurred to producers were costly. Many more examples can be given with cigarettes, halucinogenic drugs, lead poisoning, thalidomide and X-rays. The effects of these products, although not completely known, have shown definite health threats and have resulted in mental impairment and deaths. These accidents represent real losses in income, productivity and potential output, to say nothing of happiness.

Unemployment

A major cost attributed to new technologies refers to their effect on unemployment primarily due to automation. To quote Professor Crossman of Oxford University:

> Unemployment due to automation will grow steadily over the next few decades, perhaps centuries, and in the end it is likely to reach a very high figure, say 90 percent of the labor force, unless radical changes are made in the present pattern of working.[6]

Many economists do not support this view. In fact, they maintain that:

> Changes in aggregate unemployment are governed by the growth in the aggregate demand for goods and services and the growth of the labor force, as well as the growth in output per man-hour.[7]

Other economists contend that technological change has increased the skill requirements of available jobs and thus contributed to the growth of structural unemployment. Some do not subscribe to this hypothesis. Among the latter group, R.R. Nelson and E. Mansfield have carried out case studies in different industries at varying occupational levels.

> The results did not indicate any sharp or consistent increase in skill requirements as a consequence of switching to newer techniques.[8]

> More pragmatically satisfying is the evidence provided by the economic expansion which began in 1961. When unemployment fell in 1962 and again in 1964 and 1965 under the impact of expanding demand, blue collar workers, low skill workers, and those with relatively little educational background benefitted, and more than proportionately. By the spring of 1966, the unemployment rate was around 4.0 percent, below the 4.3 percent average for 1955-57, and unemployment of structurally vulnerable workers was generally about the same or lower than in 1955-57.[9]

---

[6]Organization for Economic Cooperation and Development, "The Requirements of Automated Jobs", Paris, 1965, p. 21.

[7]Mansfield, E., The Economics of Technological Change, W.W. Norton & Co. Inc., New York, 1968, p. 136.

[8]Mansfield, E., op. cit., p. 138.

[9]Nelson, R.R., Peck, M.J. and Kalachek, E.D., op. cit., p. 142.

The only cost of technological change that both authors admit is that of temporary unemployment, what Mansfield calls "labor displacement". A change in technology, say from vapor to electricity or from the latter to atomic energy, cannot prevent labor from being displaced from one occupation, industry or region to another. When firms or industries become obsolete, whole communities may suffer income losses and affect the employment in other related industries, especially in services. Consequently, production workers find themselves unemployed when their services are no longer required. The search for other work is often long, arduous and frequently results in the acceptance of a job with a reduced salary and a lower social standing than the previous one. In fact, serious adjustment problems arise and great distress can be imposed on displaced workers, such as coal miners, agricultural workers, and older people. Advances in agricultural technology have reduced the number of farmers, put farmers out of business, forcing rural workers to move to urban areas in search of illusive opportunities for work.

Nevertheless, some economists contend that, although important problems may arise in the short run, the long-run overall adjustment process is economically beneficial and that private and public policies generally help distressed workers. The high rates of unemployment in the seventies do not reflect this optimistic view, and rising discontent of the public would tend to point to these high rates as being partly attributable to the changing structure of the economy and to the speed of technological innovations.

Waste of Resources

In the continuing study of American society that has resulted in The Hidden Persuaders and The Status Seekers, Vance Packard has become increasingly aware of an even deeper malaise in American life: The Waste Makers. The third effect of successful R & D activities refers to "planned obsolescence", the central point in Packard's latter book. Explaining what is meant by those two terms, the author of The Waste Makers quotes the lament of Willy Loman in Arthur Miller's Death of a Salesman:

> Once in my life I would like to own something outright before it's broken. I'm always in a race with the junkyard! I just finish paying for the car and it's on its last legs. The refrigerator consumes belts like a goddam maniac. They time those things. They time them so when you've finally paid for them, they're used up.[10]

A further quotation by the author seems to reflect a general tacit concensus among industrialists. Brooks Stevens, a leading industrial designer, explains:

> Our whole economy is based on planned obsolescence ... We make good products, we induce people to buy them, and then next year we deliberately introduce something that will make those products old fashioned, out of date, obsolete.[11]

---

[10]Packard, Vance, The Waste Makers, David McKay Co., Inc., New York, 1960, p. 53.

[11]Idem, p. 54.

The author of The Waste Makers discusses only briefly the brighter side of the coin.

> I should stress that all which follows here does not change the fact that many hundreds of American companies still do their very best to give their buyers a long-lasting product, especially in fields not heavily dependent upon replacement sales.[12]

Vance Packard distinguishes three different types of obsolescence:

> There can be:
>
> a) Obsolescence of function. In this situation an existing product becomes outmoded when a product is introduced that performs the function better.
>
> b) Obsolescence of quality. Here, when it is planned, a product breaks down or wears out at a given time, usually not too distant.
>
> c) Obsolescence of desirability. In this situation a product that is still sound in terms of quality or performance becomes "worn out" in our minds because a styling or other change makes it seem less desirable.[13]

Packard's criticism is primarily directed to the product-making society. He shows how this society has developed the need for increased production to the point of obsession: growth for growth. He then identifies the increasing dilemna,

---

[12]Idem, p. 58.

[13]Idem, p. 55.

namely that America's capacity to produce may have out-stripped its capacity to consume. The solution adopted by industry: planned obsolescence. Packard also shows how consumers have been indoctrinated by hidden persuasion, how they were tricked by new products, new designs and new gimmicks, and how they were affected, socially and economically by these changes.

The author gives many examples and emphasizes a few. Vehicles are built so as to become defective after a period of time or to be outmoded by the second or third year; home products such as refrigerators, can openers, T.V. sets, radios, washing machines, driers, freezers, air conditioners, are planned not to last too long. Packard says that "there was specific indication that evidence of quality obsolescence was not unconnected with the drive to increase replacement sales."[14] The same thing applies in home furnishings and clothes or dishes; the large American middle class wants to be in style, not outdated. This mass of obsolescence of quality naturally results in what Packard calls "the repairman's paradise."

> As automation wiped out hundreds of thousands of jobs in goods-producing industries, the slack was being taken up to a large extent by new openings in the service industries. One of the great and growing service industries was product repair.[15]

The author reaches five conclusions. First, that "there were more things to go wrong" due to the increased number of extras and luxury features that were added to the standard

---

[14]Idem, p. 60.

[15]Idem, p. 128.

products. Second, "replacement parts were costing more". Third, "failing parts were increasingly inaccessible or hard to obtain". Fourth, that "manufacturers often failed to provide information that would facilitate repairs." Finally, that "the trend was to encourage customers to replace parts rather than to bother repairing them."

What are the implications of this technological waste? While Vance Packard has shown some of the misuses of R & D activities, Lukasiewicz examines some of the consequences of technological advances and their costs.

> We must count chemical and noise pollution, congestion of streets and highways, "explosion" of cities into suburbs with the resulting decay of city centers, the smothering effects of "freeway spaghetti" and parking lots on city communities, waste of land and fuel, degradation of countryside through profileration of roads, service stations, drive-in facilities, advertising and junkyards, prodigious costs in deaths, injuries, property damage, policing and licensing.[16]

One of the consequences is what the author calls "technological garbage". Not only are wastes produced, but they must be discarded, an added cost. Says Lukasiewicz:

> Discarded passenger automobiles litter cities and countryside to the extent no longer considered acceptable. In the U.S. about 65 percent of cars produced are being discarded... the current rate of junking of cars is about 25,000 per year per million population. In 1968, 31,578 abandoned cars were removed in New York City.[17]

---

[16] Lukasiewicz, J., Complexity and Saturation in An Environment of High Technology, op. cit., p. 16.

[17] Idem, p. 17.

The problems incurred by the high and rising costs of household garbage disposal also arise in such metropolitan areas.

> Everyday, an American throws away an average of about 5 pounds of garbage, so that some 500,000 tons per day accumulate. Disposal of municipal wastes alone costs $3.5 billion a year, or $17.50 per capita. In New York it costs $36 to collect and dispose of one ton of refuse; one ton of coal costs only $12.[18]

New York, San Francisco and Philadelphia are running out of garbage disposal space. The increasing garbage in space may also present future problems. Some 350 objects rotate in the earth's orbit. A collision of two satellites has already been recorded, and with other space projects underway, space trash may prove to be particularly expensive.

The development of new products and processes coupled with planned obsolescence, has produced a problem of waste disposals. The answer could be found through more R & D activities on disposal methods. However, this solution would only be temporary since the amount of garbage increases constantly with population and production. A more lasting solution may involve the development of new products and processes which facilitate garbage disposal or minimize wastes and reduce obsolescence.

<u>Consumer Sovereignty</u>

Successful R & D activities have led to another negative effect related to the previous one: the disappearance of consumer sovereignty. This idea is represented by John

---

[18] Idem, pp. 16 and 17.

Kenneth Galbraith. He shows that an evolutionary process has occurred in the industrial state and that the production of goods and services has been overemphasized especially since World War II. This has resulted in two related causes. First the growing specialization needed for technological advances has made management a group-decision process. Second, the increasing amounts of capital needed for specialized workers and new complex equipment materials has resulted in the elimination of small enterprises and in the advent of the big corporations, the technostructure.

> The five hundred largest corporations produce close to half of all the goods and services that are available annually in the United States.[19]

These large firms have taken over the market process and reversed the normal sequence of consumer sovereignty. They have seized power and have used it to control and regulate aggregate demand, and to manipulate the consumer mind. Their influence has even reached and affected government actions. These big corporations have exploited high pressure advertising and the want-creating process, enabling them to sell the products of their laboratories. At what costs? It has disrupted the pattern of consumer spending. Individuals have been induced to buy on credit and this behavior has been responsible for recent inflationary pressures on the economy.

---

*The "Dependance Effect" evoked by Galbraith is not a theory shared by the present author who has presented his views on the subject in a previous paper entitled "The Contribution of J.K. Galbraith to the Theories of Economic Growth.

[19] Galbraith, J.K., The New Industrial State, A Signet Book, New York, 1967, p. 14

Galbraith also claims that the concentration of large firms has almost eliminated all strong competition and that in addition to producing wants, they produce them at a determined price and in the amounts they choose. This system, Galbraith says, has made anti-trust and anti-combine laws ineffective. Finally, this economist demonstrates the decline and forecasts the future disappearance of trade unions.

Therefore, Galbraith believes that the big corporation, with its technological power, has taken over and adapted its environment to its needs and wants. However, many economists do not share his views. Mansfield is particularly critical:

> The available evidence does not seem to support this hypothesis. In most industries for which data are available, there is no indication that total R & D expenditures would decrease if the largest firms were replaced by somewhat smaller ones; there is no indication that the R & D expenditures carried out by the largest firms are more productive than those carried out by somewhat smaller firms; and there is no indication that greater concentration results in a higher rate of diffusion of innovations ... However, there is no statistically significant relationship between an industry's concentration and its estimated rate of technological change.[20]

Although Galbraith's case may be overemphasized and overgeneralized, big corporations still exist, and they yield wide powers over the economic life of society. These newly acquired powers however are not entirely due to this command over technological advances but the latter have certainly helped to strengthen the hand of the technostructure.*

---

[20] Mansfield, E., op. cit., p. 245.

*In a new edition of "The New Industrial State", Galbraith modifies his position considerably.

Alienation

The fifth effect of technological change has to do with alienation. William Faunce describes it this way:

> The most persistent indictment of industrial society is that it has resulted in the alienation of industrial man. Loneliness in the midst of urban agglomeration; loss of social anchorage in mass society; the absence of a predictable life trajectory in an era of unprecedented social change; and the powerlessness of man within the complex social, economic and political systems he has created are common themes in the social criticism of the industrial way of life.[21]

The alienation of modern man has its roots in what Eric Fromm refers to as the process of "individuation" or the "emergence of the individual in human history."

> Man was deprived of the security he had enjoyed, of the unquestionable feeling of belonging and he was torn loose from the world which had satisfied this quest for security, both economically and spiritually.[22]

What is the cause of this alienation? Ben B. Seligman relates it to the effect of advancing technology on work. He believes that

> the mode of work was increasingly directed and specified by advancing technology, it became less flexible, offering less freedom and maneuverability to the individual ... Technology is unfree, for it imposes its requirements on all others and therefore abolishes freedom.[23]

---

[21] Faunce, W.A., Problems of an Industrial Society, McGraw-Hill Book Company, New York, 1968, p. 84.

[22] Fromm, Eric, Escape From Freedom, Holt, Rinehart & Winston Inc., New York, 1941, p. 99.

[23] Seligman, B.B., "Work, Alienation and Leisure", American Journal of Economics and Sociology, October, 1965, Vol. # 24, p. 339.

Seligman and Faunce explain that work has lost much of its meaning. Work should provide a standard for judging one's worth, a method for achieving fulfilment and a way to relate oneself to society and the environment. Seligman believes that with increasing technology these qualities of work have disappeared. With growing specialization and automation,

> the human being can take part in only a limited range of activity, and is thereby denied an opportunity to relate himself usefully to others.[24]

This does not only apply to manual work but also to intellectual work.

> Let us grant that work today may be less fatiguing and occupies less time. But it is also aimless and absurd, for it has been converted into labor with virtually no resemblance to meaningful work.[25]

Therefore Seligman concludes that technology has alienated man from his work and has left income as the main motivation to work.

Scarcity of Time

Related to alienation is what Stafand B. Linder calls "the increasing scarcity of time".[27] He maintains that in striving to achieve continuing economic growth, the industrial

---

[24]Idem, p. 341.

[25]Idem, p. 348.

[26]Linder, S.B., The Harried Leisure Class, Columbia University Press, New York and London, 1970.

state has, through technological advances, raised productivity of man's efforts in such a way as to raise the yield on time devoted to all other activities. This has resulted in a growing quantity of goods and services consumed.

Technological innovations have extended the range of the individual's domain and the expansion of his territory has endowed him with more wants and obligations. Although there are faster transportation and better communication systems, the average North American spends more of his time travelling, reading, learning and assimilating information than before. The car, to take the most common example, has extended the individual's network of transportation. An individual can accept a job farther from his home, and fulfill more social obligations or wants; the general case being that this extension of the individual's domain has decreased the amount of time accorded to the performance of a particular task and increased the number of wants and obligations that this new territory has entailed. Not only is time required for the consumption of a car's use but also one must take time for the maintenance of the car: washing, gasoline, repairs, shovelling, ticket payment, and other cares which are time-consuming.

Linder distinguishes between consumption time, maintenance time, working time, personal work time, culture time and idleness. In this framework, households are producers as well as consumers of commodities, where different operations involve the combination of inputs with time. Technological advances have increased the yield on time for each of Linder's categories. These gains in productivity have increased the number of jobs possible to perform in a given amount of time and thus has made life more hectic. In Linder's words:

> Changes in the use of time will occur, so that the yield on time in all other activities is brought into parity with the yield on working time ... the necessary increase in the yield on time in the non-working activities can take place in many different ways ... A more basic and radical method of raising the yield on time used in consumption is to increase the amount of consumer goods to be enjoyed per time unit.[27]

Productivity increases have made time grow scarce and expensive. Linder concludes that leisure time has remained a luxury which entails (1) the payment of income to others for saving time or making it more productive, and (2) the foregoing of work and its income.

Technological innovation has therefore increased productivity to the point where its benefits may possess the drawback of a negative effect, i.e., increasing the scarcity of time and making life more hectic, and more stressful.

This concludes the analysis of the negative effects of R & D; both sides have been presented: the advantages and disadvantages of technological change. But the distinction between the beneficial and the adverse consequences are somewhat

---

[27]Idem, p. 4.

blurred by the fact that they affect different people unequally and in opposite ways. Furthermore, the total economic effects of R & D activities are virtually impossible to measure. But in recent times much recognition has been given to the negative effects. It may be possible, therefore, to arrive at a more impartial assessment of technological advances in the future.

However, the strong case built against technological change recently, does not constitute a condemnation of the whole process. The growing awareness and recognition of the negative effects of technological innovation has made possible the establishment and elaboration of corrective procedures. In the past, some of these effects were isolated and most countries could not forsee the consequences of the widespread introduction and diffusion of technology. Most new products and processes resulted from problem solving, as opposed to technological opportunities.[28] This interest was limited to fulfilling narrow objectives.

Today, the knowledge of their total effects on society allows the social scientist to assess more accurately the impact of most technological innovations. With this newly acquired knowledge, society may develop means to measure and control the effects of this economic factor (minimizing costs and maximizing benefits) satisfactorily, so as to reorient technological advances.

---

[28] OECD, The Conditions for Success in Technological Innovation, Paris, 1971.

CHAPTER VI

FACTORS CONTRIBUTING TO R & D ACTIVITIES

The knowledge of operations and potential economic effects of R & D activities gives the strategist of science and technology, the information necessary to compare the present scientific effort in a country with its actual economic returns. However, to elaborate new strategies, the factors contributing to the quantity and quality of R & D performance must be known. This chapter proposes to examine the motivations that stimulate both private and public sectors to spend financial and human resources on these activities. Finally it inspects the possibilities of measuring the profitability of research work by using cost-benefit analysis. If this were successful, it could greatly influence the extension and use of R & D activities.

The factors contributing to the introduction, promotion and extension of research and development operations differ in nature and goals, depending on who executes them, the private or the public sector. The first group is mainly concerned with supply and demand elements while the second relates more closely to factors concerning general welfare.

Before examining these, the relationship between two concepts must be clarified. The effect of an action often creates the reason behind the performance of that action. For example, the reduction in input prices may either be a cause and upon success, an effect of a research project. The similarity lies in the fact that they both can be objectives; the dissimilarity arises in that one aims at potential objectives and the other is the realization of these intended ends. Nevertheless, the former does not necessarily result in the latter. This chapter especially concentrates on the more important determinants of R & D activities.

1. Private Sector

This sector is mainly concerned with industrial research and development activities and those of the individual inventor. The first is an outgrowth of the second and has been increasingly institutionalized since the end of World War II. However, the difference between these two groups warrants a separate analysis.

A. Industry

What are the factors contributing to the inducement of industrial R & D performance? One word, "profitability" would almost incorporate them all; but a further breakdown is necessary. The ubiquitous market forces of supply and demand serve that purpose, and provide the framework for analysis. Supply factors include funds, management, manpower and equipment. Demand factors involve changes in quantity, and price.

i) Supply Factors

Funds. A first and particularly important factor has to do with the amount of funds available for research and development. Investment decisions in that field are made on the basis of profitability of success. Often predictions are hindered by uncertainties regarding the technical and economic feasibility. Nevertheless, the high risks of venturing in research operations offer above average potential returns. Capital, within a business enterprise, may compete with other investment alternatives and therefore, R & D must offer the greatest opportunities for profit if funds are to be channelled into that department. But even if the potential gains are substantially attractive, businessmen may decide against research investments due to its high risk propensity and choose a more conservative and safer venture. The ultimate decision depends on the type of management which heads the firm and its current financial situation.

A factor that may encourage industrial expenditures on research and development activities stems from the contention that there exists a close relationship between the amount of funds attributed to R & D and the number of significant inventions. Mansfield's study of the chemical, petroleum and steel industries supports this suggestion.[1]

---

[1]Mansfield, E., Industrial Research and Technological Innovation, W.W. Norton & Company, Inc., New York, 1968, pp. 40 to 42.

He summarizes the results in these words:

> On the basis of crude measurements that can be made ... holding size of firm constant, the number of significant inventions carried out by a firm seems to be highly correlated with the size of its R & D expenditures.[2]

Yet, other sources of funds are available, of which government is the largest. The amount of resources it devotes to support industrial R & D, depends on how closely the industry is related to the defense, public health and other social needs for which government assumes major responsibility. Universities and non-profit organizations also distribute some of their research funds to industry. Chapter III provides some details on this subject. These assistance programmes and contract work provide a strong inducement to industries to establish and conduct R & D activities.

Funds also depend on the size of the firm. The bigger the firm, the more it will spend on those activities. This claim is supported by a number of empirical studies. Both Nelson[3] and Mansfield[4] corroborate these findings with the latter concluding on a note of caution. He points out that surveys show that large firms do not necessarily engage in major technological advances. In fact there are some indications that they are largely originators of many minor improvement inventions.

---

[2]Mansfield, E., The Economics of Technological Change, op. cit., p. 67.

[3]Nelson, Peck, Kalachek, op. cit., p. 47.

[4]Mansfield, E., op. cit., p. 94.

Favorable economic prospects encourage businessmen to invest in optimistic expectations. The expansion of the money supply, relatively low interest rates, a high rate in the marginal efficiency of capital, liberal fiscal policies and increases in demand can ease the pressure on funds and induce firms to expand their activities in their search to increase profits. Such prospects, while increasing investment possibilities in general, are apt to favor research and development operations if other factors contributing to them are auspicious.

Management. A second important determinant affecting the amount of R & D activities relates to management, entrepreneurs and innovators. They as individuals or as a group decide whether or not to engage in these activities. Assuming availability of funds, this decision depends primarily on the personality of management, the type of industry in which the firm is involved, manpower and demand factors. The last two are the subject for a later discussion.

The type of industry is often a decisive factor. On the one hand a firm within a science-based industry such as chemicals and electronics must engage in the creation of new and improved products and processes in order to compete. It is a question of economic survival. On the other hand, in firms whose products are not science-oriented, management has more freedom of choice. The decision may depend on their age, experience, profession and personality. Not only can management spur the necessary enthusiasm to establish the new department but it must also possess an organization capable of effectively transforming new knowledge into technological innovations.

Once a firm has decided to engage in R & D activities its primary concern is the profitability aspect: costs, possibilities of success, approximate time of breakthrough, and alternative research projects. As projects progress, management is interested in the reduction of risks and uncertainties and in the accumulation of scientific information leading to more precise indices of profitability, not only in terms of money but also in terms of other benefits occurring to the firm.

In this case the quantity of R & D undertaken will depend on the magnitude, the size and the complexity of the advances sought. The magnitude of a project increases with the amount of required inputs, the specially-designed components and the time and manpower devoted to it. If the advance sought is ambitious, a greater number of uncertainties, misjudgments and mistakes are apt to be made. In the end, original objectives may prove unachievable, requiring that the project be scaled down or possibly abandoned as a costly failure.

Size and complexity also play a role in decision making. The research, designing, engineering and testing of a new airplane is more complex than that of a television. A larger number of components may involve more resources, and entail a greater interdependence between parts. Therefore, smaller and less intricate sought-for innovations involving fewer interdependent components are more apt to be undertaken than those incorporating major improvements in a product.

Manpower. The third supply factor contributing to R & D activities is the availability and capabilities of scientists and engineers in a country or in an industry. R.R. Nelson emphasizes the importance of an adequate supply of well-trained researchers.

> The capability to achieve technological advances in a particular field depends on the number of people possessing the knowledge needed to invent in that field.[5]

Along with the stock of materials and components, the latter author qualifies R & D manpower as "key determinants of inventive productivity". A firm may have ideas for a research program but the lack of scientists and engineers in the field may forestall its implementation. Not only should they be accessible at reasonable costs but they must also possess the relevant knowledge and enthusiastic involvement needed to carry out industrial R & D. The number of scientists and technologists and their capability is primarily dependent on the level of formal education, migration and on the present stock of knowledge. A particular advancement may be the object of a firm but its

---

[5]Nelson, R.R., op. cit., p. 34.

realization may be distant due to the lack of "connaissance" in that field. Furthermore, communications with the rest of the scientific world will keep researchers apace with scientific advances. Adequate relations between management and research personnel in a firm may increase efficiency. An amiable atmosphere is usually propitious to further increases in R & D output.

Equipment. Another supply factor relates to material components. Equipment and laboratories are a necessary prerequisite for the scientist to perform the tasks of inventive activity. The level of their sophistication and the knowledge of their use is an attribute which is only equalled by its costs. Often new equipment offers the possibilities of important testing, contributing to discoveries which would have been impossible without the help of specialized machinery. Considerable time and resources can be saved by the use of sophisticated equipment which may increase the scientist's productivity. Their availability could lead to more R & D industrial programs and to stronger competition between firms engaged in those activities.

ii) Demand Factors

Turning now to the discussion of demand factors affecting R & D activities, these may be explained as follows:

> Two factors lay behind the changes in the demand for particular advances. First, there (is) an increase in the demand for the product to which the advance was applicable. Second, there (is) a growing shortage of a factor of production which led to effort aimed at mitigating the effect of that shortage.[6]

Quantity. Increased demand for a good can contribute to market pressures for advances that are cost reducing and/or quantity improving. Such improvements in the production function may widen the overall market, offering a greater potential profit for the firms introducing such advances. Thus, the expansion of demand for a good may induce the particular firm to supply the increased demand by innovating. R & D activities may also be performed to raise the quality or reduce the cost of a product in anticipation of increased demand and profits. Shifts in latent demand may have a similar effect on the incentive for invention. The communication and transportation industry is a case in point.

Price. Growing scarcity or rising costs of a specific input can also stimulate changes in the nature of technological advances. In fact, the replacement of factors of production which are scarce and costly may increase profits and offer a possible price reduction on the final product. Labour saving more than capital saving innovations may be a continuing phenomenon conducive to technological change. This may have occurred because the cost of new machinery has tended to fall relatively to the wage rate. Nelson explains:

---

[6]Nelson, Peck, Kalachek, op. cit., p. 29.

> Thus efforts to advance technology will tend to be drawn toward reducing cost and increasing product performance in industries and classes of products where demand is rising and toward saving on factors whose relative cost is rising.[7]

Technological change appears to be the ultimate objective in the performance of industrial research activities. It is stimulated by demand pressures from consumers or from resources and permitted by the availability and capability of supply factors. Both are inducements to technological innovation.

B. The Independent Inventor

The independent inventor also contributes to advances in technological knowledge. Jewkes, Sawers and Stillerman[8] identified 61 major inventions made in the first half of this century; Hamberg[9] added 27 inventions of comparable importance which were made during the decade 1946-55. Sixty-nine or 74 percent were the product of independent inventors, small companies and individuals, in universities and government laboratories. Such inventions included air-conditioning, automatic transmission, Bakelite, cellophane, the jet engine, the ENIAC computer, stereophonic sound, Xerography and penicillin.

---

[7] Idem, p. 33.

[8] Jewkes, J.D., Sawers and R. Stillerman, The Sources of Invention, St. Martin's Press, Inc., New York, 1958.

[9] Hamberg, D., "Invention in the Industrial Research Laboratory", Journal of Political Economy, No. 71, pp. 95-115, 1963.

These findings are confirmed by studies made in particular industries. The origins of 149 inventions in the aluminium industry between 1946 and 1957 were studied by Peck.[10] Only one of seven major innovations originated in a large company; three were the work of independent inventors. Another study made by Hamberg[11] indicated that 7 of 13 major innovations in the American steel industry from 1940 to 1955, resulted from the activities of private inventors. Lastly, Enos[12] discovered that in the petroleum industry, all 7 basic major inventions, underlying past and present refining processes, were made by independent inventors. In most cases, large companies undertook the costly phases of engineering development, production and marketing for these inventions.

The concensus is that the relative and probably the absolute importance of the independent inventor may have been declining for many years due to the advent of formal R & D programs and to the increasing complexity of expensive equipment. Their smaller number may also be attributed to the fact that they are hired by organizations which perform R & D activities. Presently, private inventors are still contributing to the inventive

---

[10] Peck, M., "Inventions in the Post War American Aluminum Industry", in R.R. Nelson, ed., The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton: Princeton University Press, pp. 279-298, 1962.

[11] Hamberg, D., "Invention in the Industrial Research Laboratory", op. cit.

[12] Enos, J.L., Petroleum Progress and Profits, M.I.T. Press, Cambridge, Mass., 1962.

process, although it is difficult to estimate their number. Since 1908, patent statistics in Canada show a continuous decrease in the percentage of patents granted to these individuals as opposed to business enterprises.[13] In 1968, 36.5 percent of Canadian patents were granted to independent inventors (see Table 29). Although these figures show a definite relative decline in the number of patents accorded to them, this does not necessarily mean that the number of private inventors is decreasing. Jewkes says:

> It is indisputable that there still are notable individual inventors. But the qualitative evidence can tell us nothing of the possible trends ... Unfortunately, the relevance of patent statistics to what is really happening in the field of invention is very obscure. Indeed, were it not for the fact that no other statistical material exists, the patent statistics would properly be ruled out of court as useless.[14]

However, they may be an indication of the disappearance of the individual inventor. In any case, the independent inventor in Canada today still remains important. In the words of the Economic Council of Canada:

> D'une part les inventeurs indépendants demeurent très importants par leur nombre et peut-être plus encore par leur faculté d'en arriver à de véritables découvertes qui parfois échappent aux bataillons plus difficilement manoeuvrables de chercheurs des grandes sociétés commerciales.[15]

---

[13] Conseil Economique du Canada, Rapport sur la propriété intellectuelle et industrielle, Information Canada, Ottawa, janvier, 1971, p. 51.

[14] Jewkes, Sawers and Stillerman, The Sources of Invention, op. cit., p. 88.

[15] Conseil Economique du Canada, Rapport sur la propriété intellectuelle et industrielle, op. cit., p. 52.

Moreover, A.G. Vicas recently examined the industry of farm machinery in North America (Canada and U.S.A.). He found that in spite of the presence of oligopolistic sectors and large international enterprises, many patentable inventions were still the work of small inventors:

> The evidence presented on the important role of farmer inventors is further corroborated in a letter from Western Development Museum to the Royal Commission on Farm Machinery dated August 26, 1968. (R.W. UnRuh) lists 13 inventions made by farmers, many of them still manufactured by small firms that have become important manufacturers of one or more specialized items.[16]

Although this represents only a small sample of all industries, it, nevertheless, strengthens the position of the independent inventor. The following paragraphs deal with the main factors that lead the independent inventor to contribute to technological innovations.

The first motive, in this case also, is the profitability of discovering a new invention and applying and transforming this new knowledge. Once this is accomplished, the inventor can sell to the highest bidder or choose to undertake production himself , both carry financial rewards. The latter will usually involve added risks and possibly bring greater rewards. If the independent inventor has proven himself, industries or other organizations may want to hire his services.

---

[16] Vicas, A.G., "Research and Development in the Farm Machinery Industry", Royal Commission on Farm Machinery, Study No. 7, Queen's Printer, Ottawa, 1969, p. 32.

The sophisticated laboratory equipment of these R & D institutions may also serve to attract the inventor who does not possess the needed capital to further develop his invention. A second motive may be the recognition and fame. In Mansfield's words:

> It is recognized that, besides having economic motives, inventors invent for fun, fame and the service of mankind, and perhaps to express the instinct of workmanship or the instinct of contrivance.[17]

The reputation acquired by the discovery of a new invention gives to the scientist pride and satisfaction. In industry also, this competition between scientists is often found to be a source of relentless search and a benefit to their company. The third and last source of R & D stimulation for the independent inventor is attributed to the character of his research work. Although he is not equipped with the advantages of expensive machinery, he possesses the will, the freedom and the enthusiasm which are significant determinants in the inventive process.

2. Public Sector

The public sector consists mainly of Governments and universities. The factors contributing to the performance of R & D activities within this category differ from the private sector due to two characteristics. First, public R & D

---

[17] Mansfield, E., The Economics of Technological Change, op. cit., p. 51.

facilities are not profit oriented since the output of their laboratories is not directly concerned with production activities and market distribution. Their survival does not depend on profits but on available government funds. Second, the types of research differ from one sector to the other. Most of industry's work is performed in the development stage, while governments and others specialize in basic and applied research. Therefore, profitability does not represent the ultimate end of the public sector; the latter's objectives are more likely to be concerned with the welfare of society and the advancement of knowledge.

A. Governments

Central governments are the largest supporters of public R & D activities. In general, these activities take place in four departments: defense, agriculture, health and welfare. The order reflects the relative position in many countries in terms of the amount they devote to research.

The first need of a nation is the exigency of military defense to protect the territory and its citizens. This has been the concern of governments since the beginning of tribal life. Nowadays, the development of new and improved means of protection heads the list of priorities of most major powers. R & D operations have been especially active at times when national security was threatened by war or when international prestige was in jeopardy. The first case can be illustrated by the large amount of military research carried on during and after the two World Wars, from the development of the airplane to the emergence of the V ones and V twos. The second case is exemplified by the recent exploit of American technology to reach the moon before the USSR.

Thus, the extent of government R & D expenditures can be dependent on military protection and on international competition for technological supremacy.

The second factor contributing to public R & D consists in the provision of an adequate food supply. Government laboratories in agriculture have developed new products to fertilize the land, to exterminate destructive insects, and to prevent the spreading of plant diseases. The volume of agricultural R & D performed by government has mainly relied on the need to combat famine, insects and diseases, to increase production, productivity and food quality and to preserve limited resources.

Health is another area in which central governments are active. Research in this field is undertaken in response to social needs, namely the reduction of premature death and disabilities due to sicknesses, diseases and accidents. Cancer, heart disease, mental illness, physical impairment and drugs have been the subject of research and development to prolong life, restore health and prevent losses of work, income and leisure.

Governments also support R & D activities in the area of general welfare. Pollution of the environment is receiving increasing attention and has led to the extension of research operations in order to understand and solve the problems raised by ecologists. Scientific activities for transportation and communication systems have led to the development of satellites and space travel. Other social problems which have led to the performance of R & D, include population explosion, harmful technological effects, misuse and abuse of limited resources, etc. The future holds many unsolved problems which, due to their intensity and scope will be the responsibility of governments. This will likely lead to the extension of public R & D programmes.

B. Universities

Most of the activities done by these institutions fall under the category of basic or fundamental research. Their primary objectives are the advancement of knowledge per se and the improvement of the transmission of the present stock of knowledge. The main determinants for this research activity are (1) an adequate supply of funds from government industries and private sources, (2) a sufficient number of qualified scientists, (3) laboratory facilities, and (4) administrative policies. All four amount to what was called earlier "industrial supply factors."

Apart from these factors, the performance of university research is motivated by freedom of action, pride, personal enthusiasm and intellectual curiosity. Unlike industry these institutions are not profit oriented and are not primarily concerned with technological innovations.

3. Cost-Benefit Analysis

A final factor contributing to the performance of R & D activities concerns the measurement of their profitability. In this case the term "profitability" is limited in its meaning to the ultimate financial situation in which the relevant persons or institutions may find themselves after the full exploitation of an innovation. This includes two chronological and almost subsequent phases; first the cost of R & D and second the monetary benefits drawn from the introduction and the sales of new or improved products and processes. Such a study refers to what is commonly called Cost-Benefit Analysis.

The returns on research and development are subject to less assurance than the returns on expansion since the former entails not only economic but also technical uncertainties. Furthermore, the management of research is still in its infancy. In a survey made by Peter Stubbs[18] of forty-five companies, the firms were asked whether they tried to assess the returns to R & D expenditures.

---

[18] Stubbs, Peter, Innovation and Research, published by F.W. Cheshire for the Institute of Applied Economic Research, University of Melbourne, Australia, 1968.

> None claimed to have a really comprehensive system of assessment, covering all their activities.[19]

The main reason for this dearth relates to the simple fact that the net benefit can only be vaguely evaluated "ex post" and even more so "ex ante". Roger Demonts of the French Institut de Science Economique Appliquée states that:

> Il est possible - et peut-être bon - de se prononcer pour l'espoir, mais en l'état actuel de nos connaissances, nous sommes obligés de dire que l'analyse des coûts et rendements ne permet, dans la généralité des cas, ni de suivre ex post les coûts et rendements d'une opération de recherche, ni d'établir ex ante un ordre de préférences entre plusieurs projets de recherche. Les entreprises qui faute de mieux ont recours à cette méthode n'ignorent pas les erreurs auxquelles elle peut entraîner.[20]

Both Demonts and Stubbs maintain that Cost-Benefit Analysis can be useful when estimating net benefits of short term projects which involve minor improvements. They explain that this type of analysis rapidly looses its value as delays are prolonged and as projects aim at greater advances in science and technology. For this reason, basic research is particularly inappropriate for the calculations of costs and benefits. In the case of applied research and development, cost-benefit analysis is likely to be relatively accurate except when it deals with major advances. Industry, especially, performs these

[19] Idem, p. 140.

[20] Demonts, Roger, "Le rendement social de la recherche scientifique et technique", Chapter VIII, Recherche et Activité Economique, published under François Perroux by Armand Colin, Paris, 1969, p. 207.

estimations on the basis of day to day information, as projects advance. Most of this information is based on the predictions and justifications of its researchers but the ultimate decision rests on the good judgment of its management.

Although there are difficulties in measuring the net benefits of particular R & D projects, experience has shown that in the long run, the performance of these operations eventually results in financial rewards.

Taken as an aggregate, and if allocated efficiently, R & D activities can become a strategic economic factor leading to industrial profits and social benefits. The following chapters deal with the maximization of R & D efficiency and the allocation of Canadian scientific and technological activities.

CHAPTER VII

CONSIDERATIONS FOR A STRATEGY: BASIC RESEARCH

Canadian science policy has developed, during the last fifty years, a strategy based mainly on fundamental or curiosity-oriented research, as defined in Chapter II. This model was described at length in Volume I of the report published by the Senate Special Committee on Science Policy.[1] Successive Canadian science administrators believed that if economic growth was to be promoted through R & D activities, it was necessary to train a growing number of pure scientists in universities, to foster free academic research and to establish government laboratories to provide jobs for those who could not or who did not want to stay in universities. Industry was expected to transform scientific discoveries made by pure scientists into useful innovations and, therefore, to use basic science as a basis for industrial growth.

The Senate Committee found that such a strategy was unrealistic and that the innovation process did not work as visualized by science administrators. Their sought objectives could not be attained due to the intrinsic nature of the instrument used: basic research. This chapter attempts to show,

---

[1]Report of the Senate Special Committee on Science Policy, A Science Policy for Canada: Volume I, A Critical Review: Past and Present, Queen's Printer, Ottawa, 1970.

through an analysis of the main features of fundamental research, why this traditional Canadian approach may have been inadequate and proposes a possible new strategy for this particular type of research activity.

A. Characteristics of Basic Research

The definition of basic research given in Chapter II indicates that it has in itself no practical objective. Its immediate purpose is to make scientific discoveries and to increase the stock of speculative knowledge. It corresponds to man's intellectual curiosity and to his natural desire to understand better his own nature and his environment. To quote Professor Blackett:

> The Americans, I think, have coined the phrase "curiosity-directed research" and that expresses or is indicative of the atmosphere in which most pure scientific research is carried out.[2]

The proper climate of basic research requires freedom. The process of scientific discovery has no predetermined pattern. Therefore, it cannot be directed and planned according to practical criteria. It must be determined by a self-regulating system described by Michael Polanyi[3] as the Republic of Science. Dr. O.M. Solandt says:

---

[2]Professor P.M.S. Blackett. He was Nobel Prize Winner for Physics in 1948. Proceedings of the Special Committee on Science Policy; Phase I, the Senate of Canada; Second Session of the 27th Parliament 1967-68; p. 89.

[3]Polanyi, M., "The Republic of Science"; a selection of articles from Minerva; edited by E. Shils; Criteria for Scientific Development; M.I.T. Press, 1968.

> You do not particularly mind where it is going, because if you knew that you would not have to do it. It really would not be basic research.[4]

A second feature of basic research is that its results constitute an international free good. The stock of basic science can be envisaged as a world pool always expanding through new discoveries and which is easily accessible. Scientists are a closely knit community, desiring to publish the results of their research. By this means they can maintain communication with each other and evaluate their respective scientific contributions. The quantity and quality of the material they publish becomes a reflection of the status they have achieved among their peers. Their publications are circulated internationally, most of it in the English language. This free circulation of the results of basic research permits any country to acquire newly discovered knowledge, provided she has developed a national capability to assimilate it.

There are no patent laws restricting the use of basic knowledge, simply because it is conceptual and possesses no direct economic value that is marketable. Oriented basic research, even when it is conducted by private industry, has essentially the same feature, although it shows a closer relationship to applied research and is more directly determined by practical problems

---

[4] Dr. O.M. Solandt, Chairman, Science Council of Canada: Proceedings of the Special Committee on Science Policy, op. cit., p. 51.

than is pure research. It is a common practice both in industry and government to let scientists publish the results of their basic research.

A third characteristic which is associated with fundamental research is chance. While applied research can rely on basic science, the process of scientific discovery remains mysterious and risky. It is not easy to find new basic laws accounting for the behaviour of man and nature. The history of science shows that many important contributions to new knowledge have been made by accident. For instance, it was only by chance that Fleming discovered the phenomenon which enabled him to develop penicillin.

> I doubt that Fleming could have obtained a grant for the discovery of penicillin on that basis because he could not have said "I propose to have an accident in a culture so that it will be spoiled by a mould falling on it; and I propose to recognize the possibility of extracting an antibiotic from this mould."[5]

The implication here, is that the decision to support a pure scientist should rest on the particular ability that he has shown in the first years of his career. Jack E. Goldman has also underlined this feature of basic research:

---

[5] Dr. Hans Selye, Proceedings of the Special Committee on Science Policy; Phase I, op. cit., p. 189.

> The analogy I like to use is poker ... You play the laws of probability. To maximize your winnings, you must recognize that there are three important ingredients. One is plain, simple luck. If you are not going to get any cards, you are not going to win.[6]

Nonetheless, scientific discovery is not only a question of chance. It is also related to a high command of the existing stock of knowledge and to intuition. Relatively few people in any generation possess that knowledge and that gift, which are required to devote their life to basic research.

A fourth feature of basic research is that, within the whole spectrum of R & D activities, it is relatively inexpensive. The field of "Big Science", which consists in the gathering of large numbers of scientists on particular costly projects, is expanding. It should be left to the big powers or to international programs like CERN which involve the participation of several countries. But fundamental research is still, by and large, the preserve of "little science" where a great scientist or a small team of researchers is sufficient.

It is true, of course, that even the cost of "little science" has increased considerably in the last century. Technology has been the main source of these rising costs. Equipment for the search of new knowledge has assumed a larger role in the fields of space, energy, oceanography, geology and even

---

[6] Allison, D. (editor). The R & D Game; Chapter 14, "Basic Research in Industry" by Jack E. Goldman; M.I.T. Press, 1969, p. 201.

medicine. This phenomenon has developed to such an extent that governments and large organizations have had to give additional support for this kind of research. But comparatively to other types of research, it is less expensive.

> For any given successful project, if you have spent one dollar in basic research (in the area sense) you will spend $10.00 on product and process research, in which you have imagined a process or a project as a result of this. Then you will spend $100.00 on engineering it, getting it ready for the plant and your market studies and what not. Then you will spend $1,000.00 for the plant.[7]

There is much evidence to show that basic research is not the major source of innovations and that when it leads to new products or new processes, the time interval is usually long. This is a fifth characteristic of pure research. The OECD elaborates:

> The primary value of fundamental research, therefore is in its building up of the fabric of our culture, in moulding man's outlook on life and on himself, of contributing to the totality of human knowledge, rather than in the immediate and practical applications which it brings ... Research indeed is a manifestation of a state of mind and behavior and beyond this an expression of man's will to extend the frontiers of this consciousness to penetrate the laws of nature and to master his environment. The scientific spirit of enquiry with its ceaseless and uncomfortable questioning of fact and dogma, of assumption and tradition, is a reflection of man's highest qualities, his strivings for enlightenment and fulfilment.[8]

---

[7] Dr. Kinzel, Augustus, B., Industrial Research - Why, How and What; conference delivered on July 17, 1967, pp. 20 and 21.

[8] OECD, Fundamental Research and the Policies of Governments, Ministerial meeting on Science, Paris, 1966, p. 19.

On the basis of his numerous empirical studies, Derek de Solla Price concludes:

> It is evident to any historian of technology that almost all innovations are produced from previous innovations rather than from any injection of any new scientific knowledge.[9]

These observations do not mean that scientific discoveries have not led to numerous and important technological innovations. A great number of illustrations could be given to the contrary. Empirical evidence shows, however, that the link between the two is not as close as some pure scientists have asserted.

Moreover, when the link exists, empirical studies also indicate that the time interval required before the results of basic research have been transformed into successful innovations extends, on the average, between 20 and 30 years.

Both "Project Hindsight"[10] and its reply, "TRACES"[11] studied the contribution of basic research to many military innovations. W.R. Hibbard says:

---

[9]Price, D.J. de Solla, The Difference Between Science and Technology, Thomas Alva Edison Foundation, Detroit, 1968.

[10]Sherwin, C., and Isenson, R., First Interim Report on Project Hindsight (Summary), Office of the Director of Defense Research and Engineering, Washington, 30th June, 1966.

[11]Illinois Institute of Technology Research Institute: Technology in Retrospect And Critical Events in Science, report prepared for the National Science Foundation, NSF - C535, Washington, D.C., 1969.

> The study (Hindsight) covered the technical basis of 20 new military systems. It concluded that contributions from research in science were greatest when the effort was oriented - that it frequently takes 20 to 30 years for basic research to show up in technology ... (TRACES) reported that key research often took place 20 to 30 years prior to the innovation.[12]

J. Languish[13] and Frank Lynn[14] concur with these findings. This long time lapse is sometimes explained by the educational cycle, 20 to 30 years, and thus could suggest that most inventors rely heavily on information created in the previous generation. The thirty year cycle may also be due to the fact that the technological relevance had not been completely understood, that other scientific discoveries were necessary to produce the invention or simply that market needs were not ripe for the products or processes that could have been developed from the new basic discoveries.

Given these characteristics of basic research, the question arises as to why it should be carried out and why governments should support it. Dr. King of the OECD stated that:

---

[12] Hibbard, W.R., Materials R & D: Planning, Programming, Budgeting and Measurement, conference of October 1969.

[13] Languish, J., Case Studies of Five Innovations Which Earned the Queen's Award to Industry, 1966. British Association for the Advancement of Science, Annual Meeting, Leeds, 1967.

[14] Lynn, F., "An Investigation of the Rate of Development and Diffusion of Technology in Our Modern Industrial Society", Report of the National Commission on Technology, Automation and Economic Progress, Washington, D.C., 1966.

> The importance of basic research for the maintenance of science cannot be overestimated. This sector is important for two reasons. First of all there is an increasing appreciation that unless a country does sufficient fundamental research to attain a certain level of scientific awareness it is unlikely to be successful in applying the results of knowledge whether they be domestic or foreign sufficiently quickly and sufficiently well, ... Its second importance is that it is this independent part of the scientific effort which produces, through the educational and training systems, the people who will put science into effect.[15]

In other words, basic research must first be encouraged in order to develop and maintain a national science capability which would enable a country to at least assimilate and use new knowledge. In sustaining this national capacity, universities have a leading role to play in transmitting the present stock of knowledge to future scientists and in creating or stimulating the creation of new knowledge. Sometimes called academic research, basic research has an important mission to fulfil in linking both the young and the old scientists as well as present and future knowledge.

Secondly, since basic science constitutes an international pool, freely accessible to all nations, there is also an obligation for each country to contribute to that pool according to its financial and scientific capacity. Canada, as an

---

[15] Dr. A. King, Proceedings of the Special Committee on Science Policy, op. cit., p. 269.

advanced country has a definite responsibility in this respect. This is analogous to the obligation that Canadians have to participate in a collective defense system required by national security.

Thirdly, the leading firms in industry must carry out oriented basic research, if they want to maintain their leadership. At least five reasons justify such an undertaking. The first is purely defensive: fundamental research, in the long run, can serve as a protection against competition, obsolescence or the danger of being caught unawares by a new discovery. The firm's laboratory can maintain communication with the scientific world and concentrate on new discoveries which are in the long term interest of the company. Second, basic research can lead to successful innovations and give the originating firm a comparative and monopolistic advantage, at least for several years, over its competitors. Third, if an enterprise attracts qualified scientists with high academic standing and provides them with the proper motivation and environment, they may gradually become more interested in applied research and development and thus produce more tangible and immediate results as they become more mission-oriented. Fourth, basic research, as mentioned before, can bring unexpected discoveries and provide to a firm new possibilities for diversification. Fifth, by maintaining a basic research capability, a company is assured of a basis to complement its technical employees and assess their competence.

The arguments in favour of basic research in universities, in large enterprises and in public laboratories also serve to justify the financial support of the government for this type of R & D activity. Those reasons have been summed up by Michael D. Reagan in these terms:

1. Intellectual and cultural values of science.
2. The utility of basic research as the foundation of all technological development.
3. Research as an essential component of graduate education.
4. The high cost of scientific research and the unlikelihood of adequate private financing.
5. The political values of science, especially in international affairs.[16]

B. The Characteristics of Pure Scientists

The preceding analysis of the main features of basic research needs to be complemented by a description of the character and behaviour of the pure scientist. Here again, empirical evidence will be used because it often contradicts a priori conceptions, based on personal impressions. Most of these studies have been made abroad which illustrates the fact that Canada, in this respect, is more under-developed than some other countries. It can be safely assumed, however, that the pure scientist does not behave very differently from one country to the other so that observations made elsewhere may apply equally well to the Canadian scene.

---

[16] Reagan, M.D., Science and the Federal Patron; Oxford University Press, New York, 1969, p. 36.

B.E. Noltingk gives an idealistic description of the pure scientist:

> The scientist, no less, by his patience and ingenuity in marshalling the factors so that simple conclusions can be drawn from complex data, has achieved - either on paper or at the experimental bench - a specific aim. It is not, therefore, surprising that pure science has always its devotees. Those who are gripped by the wonder of the universe around them, possessed of a restless curiosity and a bent to analyze, keen to pit the strength of their minds in siege against the mysteries that have held out longest, confident that new vantage points will lead to conquest, they will find the pursuit of pure science a compelling and inspiring exercise.[17]

This description certainly fits the character and aims of dedicated scientists. But a number of researchers, involved in basic research, tend to emphasize altruistic goals to attain public funds and use them to pursue their own research projects. Many have contempt for those who devote their lives in development work in industry. They want complete freedom because they pretend to serve the noblest objectives of the international community and to be the main contributors to the general welfare.

However, reality seldom conforms to the ideal. The complete freedom and autonomy that pure scientists cherish does not always coincide with high performance, although they are generally recognized as an essential requirement by the

---

[17]Noltingk, B.E., The Art of Research, Elsevier Publishing Company, Amsterdam, 1965, p. 4.

conventional wisdom. D.C. Pelz has put this view to a test. He investigated some one hundred Ph.D's of whom about half worked in government and the others in universities of the U.S.A. He concluded:

> I had expected that people with high autonomy would have higher than average performance. But this was not necessarily the case. Further, one might expect that a scientist who allowed his colleagues to have some weight in deciding his goals would perform less well than the fellow who set his goals himself. In a very tentative way, it appeared that better performance occurred when influence on important decisions was shared with several persons at various levels.[18]

The survey also showed that a scientist's performance does not decline as more people influence his decision-making and goals. On the contrary the quality of his work improved. Among the patterns of decisions (self, colleagues, chief and executives) the most fruitful combination was that of self and colleagues as opposed to the worst, that of self and chief or executives.

Examining the effect of diversity on creativity or productivity, Pelz and Andrews observed:

> The scientists we have examined were most effective if they had several interests, less effective if they were highly specialized ... Except for those people who told us they had no areas of specialization ... We see that performance went up as areas of specialization went up.[19]

---

[18] Pelz, D.C., "Freedom in Research", edited by David Allison in The R & D Game; the M.I.T. Press, 1969.

[19] Pelz, D.C., Andrews, F.M., "Diversity in Research", edited by D. Allison in The R & D Game; the M.I.T. Press, 1969.

Contrary to the axiom of the conventional wisdom, the same authors found that the best performers appeared to be those who did not concentrate exclusively on their research and who spent about one half to three quarters of their time in research and the rest in administrative or teaching work.

Finally, pure scientists tend to communicate and to appraise the quality of their work through the means of publication. Although "scientists like to work in large groups they find it stimulating and interesting, and, of course, it gives them better job opportunities",[20] they remain isolated from the rest of the world, publish their findings and read those of their fellow scientists:

> The scientific literature in a given field tends to form a closed universe; workers in a field, when they criticize each other, tend to adopt the same instated assumptions.[21]

With the mounting number of scientific papers, these researchers hardly have time to keep up with all the new discoveries. In fact, some universities and organizations find it necessary to rely on the wide facilities and information providing capacities of computors. On the basis of this publication-communication process, attempts are being made to appraise the performance of scientists. Explained Dr. King, Director for Scientific Affairs at OECD:

---

[20] Dr. O.M. Solandt, Proceedings of the Special Senate Committee on Science Policy, op. cit., p. 48.

[21] Weinberg, A.M., "Criteria for Scientific Choice", a selection of Articles from Minerva; edited by E. Shils: Criteria for Scientific Development, the M.I.T. Press, 1968, p. 24.

> Counting scientific papers, if qualified by citation surveys - i.e., how often a paper is quoted by other scientists, which is a mark of quality if you like - does give a measure of the output for basic research.[22]

Whatever the value of this measurement, experience shows that pure scientists primarily seek fame and recognition through their publications and through public awards, including the Nobel Prize; pay, within certain limits, is relatively unimportant to them.

C. A Strategy for Basic Research

The preceding analysis of the features of basic research and of the behaviour of pure scientists now serves to indicate some elements of a strategy that could be used in a realistic science policy. An attempt is made to answer the following questions. How much basic research should be done in Canada? In what fields and institutions? Who should provide the funds? How can Canada profit most from the basic research performed abroad?

In 1967, Canada spent 23.1 percent of all her R & D expenditures on basic research. Among the most advanced nations, that country came first in this respect. The same ratio was 11.0 percent in the United Kingdom and 14.1 percent in the United States.[23] Is it right for Canada to devote such a relatively high percentage of her science effort to basic research? Says Professor Blackett:

---

[22]Dr. A. King, Proceedings of the Special Senate Committee on Science Policy, op. cit., p.

[23]Senate Special Committee on Science Policy, op. cit., p. 125.

> So far as I know one cannot say in apportioning a budget for pure science that it should be X percent or Y percent of the G.N.P. I doubt if there are enough good people available in most countries to justify spending much more, say, than 0.5 percent of the G.N.P. on pure curiosity directed science. Pure scientific research done by people who are not very good will itself be not very worthwhile.[24]

Similar views are put forward by Dr. Solandt:

> But scientists have only so many ideas as to how to tackle a problem, and as long as all the good scientists are supported in pursuing all the good ideas they have, more money is just a waste of time. So money is not always the determinant in how fast we can go in science.[25]

Nevertheless, some amount of money must be determined in support of basic science in Canada. To base it only on the number of scientists may only re-enforce the existing tendencies to produce a surplus of scientific manpower. To adopt a certain amount on the basis of G.N.P. only, does not take into account the number of qualified scientists and the needs for this type of R & D activity. Both must be taken into consideration, but ultimately, international comparisons should be the determining factor.

Every country should spend enough on basic research to maintain a national capability in the fields which correspond to national needs. Otherwise, as indicated before, it will not

---

[24]Prof. P.M.S. Blackett, Proceedings of the Special Committee on Science Policy, Phase I, op. cit., p. 89.

[25]Idem, p. 46.

be in a position to assimilate and apply the flow of knowledge coming from the international pool. In addition, an advanced nation like Canada should spend enough for this purpose to contribute to the expansion of that pool and thus meet its international obligation. It should not go beyond that point, however, because the results of basic research conducted abroad are free, readily available and without any risk. An indigenous effort does not offer the same advantages. Thus, given the characteristics of basic research, a small country like Canada has no obligation and no need to spend more, in relative terms, than other similar countries. She ought to devote less resources proportionally than the U.S.A. Even if she spent more, her greater effort would have only a marginal effect on the international pool compared to the major impact that the United States could have. It is clear, therefore, that the present Canadian budget devoted to basic research is too high. A relative decline, even if it were substantial, would not necessarily mean a reduction in absolute terms, if Canadians were to decide to increase their total science budget in proportion to G.N.P.

Once the proportion of resources that should be devoted to basic research has been determined, the next step is to select the fields to be supported. A first principle could be:

> That though a country should not strive to fill every gap, it needs a large enough spread of scientific interest to give it a reasonable understanding of the broad lines of scientific advance elsewhere in the world.[26]

But beyond the development of such a general capability, Canada should try to be highly selective and to concentrate on basic research oriented towards her long-term needs and her unique position in the world. This is a second principle that we should use as a guide. Canada is relatively small in terms of economic power; its percentage share of the world's G.N.P. is 2.2 percent and it has only 3.2 percent of the scientists. The U.S.A. contributes 32.8 percent of the world's G.N.P. and 41.5 percent to the international scientific community.[27] Dr. Solandt says:

> On the other hand, it is quite clear that research and the use of science will contribute more to Canada if we become leaders in certain fields. And, as I see it, all we need to do is to have a broad base to couple us to the world scientific community and some narrow peaks of excellence where we are world leader.[28]

Dr. Solandt has suggested the following fields as corresponding to unique Canadian needs and capabilities: communication, weather and resources satellites, transportation,

---

[26] Carter, C.F., "The Distribution of Scientific Effort", edited by E. Shils in Criteria for Scientific Development, M.I.T. Press, 1968, p. 36.

[27] Price, D.J. de Solla, Measuring the Size of Science; delivered to the Israel Academy of Sciences and Humanities, February, the 11th, 1969, p. 21.

[28] Dr. O.M. Solandt, Proceedings of the Special Committee on Science Policy, op. cit., p. 47.

water resources, computer science, northern resources and human environment. Some of these programs would seem more appropriate for applied research and development. Other agencies have made similar proposals. However, it would be impractical to make a selection on this basis in the absence of a government statement on national goals.

A third criterion is the national capability for excellence in basic research. The quality of the scientist rather than the research field should serve as the basis for the selection of support.

> We see it occasionally in the United States, where Congress will decide to give more money, say to research on cancer than scientists have asked for because Congress thinks it is terribly important. But scientists have only so many ideas as to how to tackle a problem, and as long as all the good scientists are supported in pursuing all the good ideas they have, more money is just a waste of time.[29]

A fourth principle is borrowed from Alvin Weinberg's concept of scientific merit:

> Empirical basic sciences which move too far from the neighbouring sciences in which they are imbeded tend to become "baroque". Relevance to neighbouring fields of science is, therefore, a valid measure of the scientific merit of a field of basic science. Insofar as our aim is to increase our grasp and understanding of the universe, we must recognize that some areas of basic science do more to round out the whole picture than do others.[30]

---

[29] Dr. O.M. Solandt, Proceedings of the Special Committee on Science Policy, op. cit., p. 46.

[30] E. Shils in Criteria for Scientific Development, M.I.T. Press, 1968, p. 27.

Weinberg sums up these guidelines by listing two internal and three external criteria. The former include: (1) "Is the field ready for exploitation? (2) Are the scientists in the field really competent?"[31] The latter refer to technological, scientific and social merit. Weinberg admits that the last criterion raises special difficulties because it involves "values of society". It is difficult indeed, especially in a democracy, to reach agreement on a set of values, of goals and priorities.

The third element of a strategy for basic research, besides the determination of the budget and the selection of programs, is related to the choice of the performance sector. The concensus of opinion favours university laboratories as the main centres of basic research. Since Canada has a small number of independent firms which are world leaders, it would be unrealistic to expect that the industrial sector would profit by making a significant effort of its own in this area. Further, the weak link between scientific discovery and innovation does not offer a strong incentive for private firms to engage into this type of R & D activity. On the other hand when basic research is carried out in universities, it has the additional advantage of providing an excellent opportunity to train new scientists and to initiate them to research methodology.

---

[31] Idem, p. 115.

Finally, government laboratories could do basic research to complement the effort made in universities and to strengthen mission-oriented programs needing new scientific discoveries. However, this kind of research performed in the public sector does not have the same beneficial side-effects that it provides when it is carried out in universities. This conclusion is confirmed by Dr. Solandt:

> In general, although these are obvious exceptions to this rule, basic research should be done in universities or close enough to them that graduate students can have access to it and profit from it.[32]

However, if universities are to fulfil their mission in this area more effectively and to carry out multi-disciplinary programs, they may have to make important institutional changes. To illustrate:

> We suffer very much in the scientific community from institutional rigidity. I could regale you with horror stories about this related to government, industry and universities. I am not picking on any part of the scientific community. I know of nothing more rigid than the departmental organization of most of our universities.[33]

The last element of a strategy for basic research to be mentioned here has to do with the gathering and the diffusion of domestic and international information in this area. Undesirable duplication must be avoided and a good

---

[32] Dr. O.M. Solandt, Proceedings of the Senate Special Committee on Science Policy, op.cit., p. 51.

[33] Dr. O.M. Solandt, Idem, p. 51.

communication network can considerably facilitate the work of Canadian scientists, since they form a very small proportion of the researchers in the world. For these two reasons, Canada must possess an adequate centre and network well equipped for gathering, storing, processing and transmitting scientific information. This service is essential to ensure the efficiency of the national effort in basic as well as in other areas of research and development. The Tyas Report[34] has concluded that this was an urgent need for Canada. In implementing this recommendation, the government has decided to assign the responsibility for creating the new system to the National Research Council. Doubts have been expressed about the wisdom of this decision because NRC has not been a great success in the past as a co-ordinating agency. It might have been preferable for the government to accept the further proposal contained in the Tyas Report that the centre be responsible to the Science Secretariat, which is closer to the central process of decision-making and therefore in a better position to develop an integrated single system.

The analysis presented in this chapter has shown that basic research was only one possible source of innovations, that it was not the main one and that a long time interval was usually required before a scientific discovery

---

[34] Science Council of Canada; <u>Scientific and Technical Information in Canada</u>, Part I; Special Study No. 8; chairman: M.J.P.I. Tyas; Queen's Printer, Ottawa, 1969.

could be transformed into new products or new processes. It has also pointed out that the output of that research was published in international journals and thus was readily and easily available as a free good to any country in the world. For these two main reasons and others, a science strategy aimed at economic and social (health, poverty, pollution, etc.) innovations should not put a high priority on this type of research. Canada has erred in this respect in the past and should now reduce substantially the relative share of her national R & D effort devoted to this area.

Other elements of strategy have been reviewed. They suggest that Canada should maintain a general scientific capability assisting a large number of scientists, especially at the beginning of their career. Furthermore, this country should develop fields of excellence corresponding to her capacity*and give special support to great scientists who have proven their talent for scientific discovery. The criterion of social merit has not been applied systematically in Canada and in the past, some scientists have had to make political choices. This weakness has been underlined by the Senate Committee and has been attributed to the inefficient central machinery of the government for science policy formulation.

Other improvements have been suggested such as structural changes in universities to deal more effectively with multi-disciplinary research programs. The creation in Canada of a single and well-integrated system of scientific

---

*and potential capability.

information should serve researchers and also the administrators who are responsible for the allocation of research money. The Senate Committee asserted in its report that Canada had a "science policy by accident", which means that there was no strategy for determining the level and distribution of R & D funds. Perhaps the suggestions made in this chapter could form the beginning of the development of a more conscious and realistic strategy for basic research in Canada.

CHAPTER VIII

CONSIDERATIONS OF A STRATEGY (CONTINUED): APPLIED RESEARCH AND DEVELOPMENT

This chapter follows the general approach applied in chapter VII but it deals with applied research and development. It intends to outline the main characteristics of these types of R & D activities and of the engineers and technologists who practice them. It also attempts, on the basis of this analysis, to present some elements of a strategy that Canada could develop in these areas in order to maximize the benefits to be derived from her national science effort.

A. The Main Characteristics of Applied Research and Development

The concept of applied research is not easy to identify in practice. It is contended by some experts that the distinction between this type of activity and basic research has little value:

> In institutions whose missions include the application of research results to products or operations the categorization of research into basic and applied is not too meaningful, and has little operational value. Industrial and government researchers feel particularly strongly on this point because, from the standpoint of research management, the basic-applied dichotomy tends to focus attention on the wrong issues. In fact, all research in a mission-oriented organization contributes or should contribute, however remotely, in time, to the general objectives of the organization.[1]

---

[1] Brooks, H., The Government of Science, M.I.T. Press, Cambridge, Mass., and London, England, 1968, p. 281.

Dr. Brooks admits, however, that when an organization has been assigned a practical mission, the research it undertakes must be useful and produce tangible results. Dr. Solandt emphasizes this point:

> Another problem I would like to dwell on at a little length, because it is so important, is that in applied research of any kind, wherever it is done, whether it is in government, universities or in industry, the first test as to whether it is good research is whether it is relevant. That is, if you get the answer, is it going to solve some important problem, social or economic? Because, if it is not, then do not do it.[2]

In other words, applied research clearly belongs to the processes of invention and innovation and, as such, its features and requirements are much closer to development activities than to basic research. That is why in this section, the emphasis is given to the characteristics of development work which can be more easily identified.

The first feature of development is that it is essentially creative. It is designed to invent new products and processes as opposed to basic research which attempts to discover and explain phenomena in a new way. Development is expected to solve concrete problems and to meet clearly defined economic or social objectives. The new or improved products and processes entail potential benefits to those who have invested funds to develop them.

---

[2]Dr. O.M. Solandt, Proceedings of the Special Committee on Science Policy, Phase I, op. cit., p. 51.

Thus, by its very nature, development is directly linked with inventions and innovations and the time interval necessary to transform development work into a new product or a new process is relatively short. This is a second feature of this type of R & D activity. The lag from invention to innovation is of strategic importance, because it partly determines the lead time that the innovative firm can enjoy over its competitors. This critical period has varied substantially in the past due to the fact that some inventions involve changes in tastes, investment in new plants and equipment and pricing problems before they could be utilized profitably. Furthermore, the length of the lag may be influenced by the character of the invention, whether it involves a major departure from current practices or whether it merely means a more routine improvement.

Another important source of possible delay is when the inventor and the innovator are not the same. This phenomenon is not infrequent as Professor Blackett says:

> It must be remembered that the money made out of inventions is very often made not by the inventor but by the next one along. The Bell Telephone invented transistors, but it was the Japanese who really went to town on them.[3]

Three main reasons can be given to explain this phenomenon. First, the inventor may not possess the resources required to launch the innovation, refuse to take the risks involved, or not be aware of the potential applications of his

---

[3]Prof. P.M.S. Blackett, Proceedings of the Special Committee on Science Policy, op. cit., p. 94.

invention. A second possibility is that another person or firm, having discovered the invention, acts more quickly and effectively than the inventor to exploit the new idea. This can occur through well-organized information channels or even as a result of industrial espionage. Thirdly, a laboratory may develop a new invention that has no use for its organization but offers real advantages to others. James R. Bright has found that especially "radical technological advances spring from unlikely sources, and often from outside the industry most seriously affected."[4] (see Table 31)

In spite of the wide differences that can exist from one case to the other, attempts have been made to estimate the average time interval between inventions and innovations. John Enos has found that this lag averaged eleven years in the petroleum industry and about fourteen years in other sectors.[5]

Even if these estimates tend to vary, the time interval between inventions and innovations remains much shorter than the period required to transform a scientific discovery into an innovation. This difference must be taken into account if the main objective of a science strategy is to produce economic and social innovations.

---

[4]Bright, J.R., Research, Development and Technological Innovation, Richard D. Irwin, Inc., Homewood, Illinois, 1964, p. 379.

[5]Enos, J., "Invention and Innovation in the Petroleum Refining Industry", The Rate and Direction of Inventive Activity, Princeton University Press, 1962.

A third characteristic of development work is that it is conducted in secret and that its results are seldom published. The reason for secrecy lies behind the fact that this type of work aims at the production of market-oriented innovations. The firm engaged in development activities does not want its competitors to know the results of its work. Innovation gives to an individual company a lead time during which it may possess specific monopolistic advantages. The new product or process can be protected by a patent.

All countries offer such a protection. Canada established its first patent system in 1823 and became a member of the International Convention for the Protection of Industrial Property in 1883.

> In Canada, a patent grants the right to control the use of any new useful art, process, machine, manufacture or composition of matter. It is not granted for products with an illicit intent nor for scientific or abstract principles.[6]

Every patent granted under the Patent Act prescribes:

> The exclusive right, privilege and liberty of making, constructing, using and vending to others to use the said invention, subject to adjudication in respect thereof before any court of competent jurisdiction.[7]

But even if the invention is not patented, it may take several years before imitations can be sold on national and international markets. This lapse of time allows the innovator

---

[6] Economic Council of Canada, Report on Intellectual and Industrial Property, January, 1971.

[7] Extract from the Patent Act, Section 46.

to make higher profits and to establish a special position on markets that imitators may find difficult to infiltrate. However, in the case of the "Product Cycle", enunciated by Professor R. Vernon of Harvard University, less developed countries may possess certain advantages in imitating. As the innovation becomes standardized, these imitating countries may present strong price competition and become net exporters to the innovating country (see Chart II, p. 206).

The secrecy of development activities is in contrast with the wide publicity given to the results of basic research. This feature has important strategy implications, since the pool of practical knowledge is less accessible than the international pool of pure knowledge. This often means that there is no alternative to an indigenous effort in development, if a country wants to succeed in the field of market-oriented innovations.

A fourth characteristic of development is associated with the relatively low risk it usually involves. But there is no unanimity of view in this respect. One school of thought believes that development activities can be effectively planned to achieve the objective desired with a minimum of risk. It is characterized by such concepts as "the management of research", "cost-benefit ratios" and "systems analysis". Another school, while admitting the need for some planning, stresses the non-rational elements in the process of innovation. Harvey Brooks describes it thus:

> Once a process of technical development has begun, it does not usually move in a straight line, according to plan, but makes unexpected twists and turns. It lays emphasis on the unexpected boundaries of need and technology, on the fact that invention often consists in carrying techniques in modified form from one field to another and that we cannot expect answers only from technologies traditionally associated with a problem.[8]

J.R. Bright, as quoted previously, makes the same point. Summer Myers and Donald Marquis arrive at similar conclusions:

> In general, minor improvements can be programmed in somewhat the same way that a job shop responds to customers' requirements. Major innovations on the other hand are quite unpredictable and high-risk ventures.[9]

Both schools of thought carry an element of truth. The fact is that they do not emphasize the same stage of development. The earlier the phase of this type of R & D activity, the more chances there will be for possible deviations from the original planned path. But as development work becomes closer to the production stage, the possibility that it will experience 'twists and turns' diminishes and the probability that events will develop as expected,rises. Thus, although major innovations may be quite unpredictable, especially in their early stage, it is safe to conclude that development work, as it progresses, is a relatively less risky operation than basic research.

---

[8]Brooks, H., The Government of Science, op. cit.

[9]Myers, S,, Marquis, D.G., Successful Industrial Innovations, A Study of Factors Underlying Innovation in Selected Firms for the National Science Foundation, U.S. Government Printing Office, Washington, D.C., 1969, p. 58.

The phenomenon of technology transfer is in a way related to the risk involved in development activities and to the whole innovation process. As such, it deserves to be mentioned here. Technology transfer includes both hardware, machines and physical equipment, and software, the organization and systematization of ways of doing things, or non-material technology. This process may take two forms. New technology can come from scientific knowledge or from a new improvement or adaptation of existing inventions. Brooks identifies the first process as a vertical transfer and the second as an horizontal transfer. He explains:

> Vertical transfer refers to the transfer of technology along the line from the more general to the more specific. In particular it includes the process by which new scientific knowledge is incorporated into technology and by which a "state of the art" becomes embodied in a system and by which the confluence of several different and apparently unrelated technologies, leads to a new technology.
>
> Horizontal transfer occurs through the adaptation of a technology from one application to another, possibly wholly unrelated to the first.[10]

The historian Derek J. de Sola Price recognizes the same two patterns but asserts that horizontal transfer is more common:

> Since it seems obvious that technology is related in some way to science, and that it grows at much the same rate by any reasonable measure, it must follow (or lead) the <u>cumulating structure of science</u>. Now, the naive

---

[10] Brooks, H., <u>The Government of Science</u>, op. cit., pp. 255 and 256.

> picture of technology as applied science simply will not fit all the facts. Inventions do not hang like fruits on a scientific tree. In those parts of the history of technology where one feels some confidence, it is quite apparent that most technological advances derive immediately from those that precede them. It may seem to happen from time to time that certain advances, particularly the spectacular and anomalous mountain peaks, as with science, derive from the injection of new science. In the main, however, old technology breeds new in just the same way as the scientific process already described.[11]

He describes science and technology as though they behaved like a pair of dancers to the same music, not knowing who leads or who follows. "The well-known lag between scientific and technological advance would seem to indicate that the dancers hold each other at arm's length instead of dancing cheek to cheek."[12] Therefore, de Sola Price concludes that there exists a considerable lag in the weak interaction of science and technology and,

> that this is in contrast to the rapidity with which new technology arises directly by strong interaction from old technology and the similar process by which old science generates new.[13]

The fact that horizontal transfers are more common and more rapid than vertical transfers reinforces the view expressed previously that development work can be much more important and useful than basic research for a national science effort aimed at economic and social innovations.

---

[11]Price, D.J. de S., "The Structures of Publication in Science and Technology", edited by W.H. Gruber and D.G. Marquis; Factors in the Transfer of Technology; M.I.T. Press, Cambridge and London, 1969, pp. 96 and 97.

[12]Idem, p. 98.

[13]Idem, p. 99.

The fifth feature of development work which is mentioned here has to do with its cost. It is generally agreed that it is the most expensive operation in the whole sequence of innovation, especially if it is defined to include engineering and design, tooling and start-up manufacturing and marketing expenses. Kinzel has already been quoted to that effect in the previous chapter. The ad hoc Panel on Invention and Innovation included some "rule of thumb" figures for the distribution of costs in certain successful innovations.[14] These figures are reproduced in Chart I.

This feature of development operations is important to note when it comes to the allocation of funds in an overall science budget. If insufficient funds are attributed to the last and more costly stage of the innovation process, innovations will not take place and the money devoted to mission-oriented research will be wasted.

B. Applied Research and Development Personnel

Applied research and development personnel may be grouped into four occupations: scientists, engineers, technicians and supporting personnel. However, the work they accomplish does not restrict them to their domain. Applied research work can be performed by pure scientists, and engineering work by

---

[14]U.S. Department of Commerce; Technological Innovation: Its Environment and Management, U.S. Government Printing Office, Washington, D.C., January, 1969, p. 9.

technicians, or vice versa. Whatever their task in the organization, this group of men is working together towards the same goal, technological innovation. Usually, however, the engineer and the technologist dominate the scene of this R & D area and the analysis contained in this section will be limited to the character and habits of these two types of personnel. They are very much alike because technologists often are trained engineers or at least use the same approach.

The professional background, the behaviour and the motivation of a competent technologist are considerably different from those of a qualified pure scientist. The reason lies in the fact that their respective activities serve different purposes and do not have the same requirements. The pure scientist seeks new scientific discoveries. The technologist is involved in the creation of new or improved products and processes. Price explains in these terms:

> The scientist, it was remarked, is heavily motivated to publish - this is the key to all the inner springs of his drive to do science. In technology it is otherwise; the tradition, crudely speaking, is to conceal in order to have a new product or a process before others.[15]

Furthermore, scientists hear from their Invisible College[16] and do not have to read published journals which are outdated already by the time they are received. Technologists

---

[15]Price, D.J. de Solla; "The Structure of Publication in Science and Technology", op. cit., pp. 95 and 96.

[16]The Invisible College refers to that small number of good scientists who are responsible for most of the scientific papers in quantity and especially in quality in a particular field.

however are eager to receive information but reveal little themselves. In fact, they try to prevent others from applying their findings by the use of the patent system. Price summarizes this phenomenon in an aphorism:

> The scientist wants to write but not to read, the technologist wants to read but not write.[17]

Thomas J. Allen stresses that oral communication is much more important than literature as a source of new technological ideas and that the average engineer, unlike the scientist, pays little attention to his professional journals.[18] He concludes that:

> Better performing groups rely more than the poorer performers upon sources within the laboratory (the technical staff and other company research programs) as contrasted with sources outside the laboratory.[19]

Myers and Marquis,[20] along with R. Isensen,[21] also emphasize the importance of personal contacts as the principal source of information for successful innovations. The first

---

[17]Price, D.J. de Solla, "The Structures of Publication in Science and Technology"; op. cit., p. 96.

[18]Allen, T.J., "The Differential Performance of Information Channels in the Transfer of Technology"; Factors in the Transfer of Technology, edited by W.H. Gruber and D.G. Marquis; M.I.T. Press, M.I.T. Cambridge, Mass., and London, England, 1969, p. 137-154.

[19]Idem, p. 153.

[20]Myers, S. and Marquis, D., Successful Industrial Innovations, National Science Foundation; U.S. Government Printing Office, Washington, D.C., 1969.

[21]Isensen, R., Some Notes on Creative Scientists and Engineers and the Growth of Technology, paper presented at the conference on "La Conception et la Création et la Gestion des Programmes de Recherche Scientifique", NATO Defense Research Group, Paris, 28th November, 1967.

two authors also found that 70 percent of the information used in the innovation process was already available from prior work. This conclusion concurs with Price's findings about the cumulative process of technology transfer.

Thus, to complete Price's former statement, it could be said that the scientist writes and reads while the technologist talks. In addition, it must also be observed that while the engineer may be as proud of his invention as the scientist is of his discovery, he is usually more interested in monetary gains. In contrast with his scientist colleague, he also prefers to belong to a team and to be given a mission, as a practical challenge to meet.

These observations tend to show that the scientist and the technologist are parts of two different worlds, even when they are called to participate in the same sequence of the innovation process. These differences in behaviour and motivation become important for the proper management of R & D personnel and for the organization of a total system of scientific and technological information. Their implications will be underlined in the next section.

C. Some Elements of Strategy for Applied Research and Development

To turn now to a discussion of the requirements necessary to establish a strategy concerning these areas of R & D activities, the following points will be considered: (1) the size and allocation of the budget in Canada, (2) the selection of programmes, (3) the sectors of performances and (4) scientific and technological manpower. The discussion of these four topics will be brief and somewhat elementary, because the science of science or "scionomics" is still in its infancy. The use of its contribution as a basis for the formulation of strategy is even more recent.

1. The Size and Allocation of the Budget

In 1967, Canada spent $896 million on total R & D activities, or 1.4 percent of G.N.P.[22] Out of these expenditures, 38.0 percent went to applied research and 38.9 percent to development. On the basis of the ratio of G.N.P. devoted to total R & D and of the share assigned to development, Canada holds the second last place, before Belgium, among the ten O.E.C.D. countries selected by the Senate Committee. While Canadians spent 38.9 percent on development, the U.K. and the U.S.A. assigned about 65 percent of their national effort to this purpose. Similar international comparisons between sectors of R & D performance indicate that Canadian business has the lowest share (37.7 percent)[23] and the Canadian Government the highest (35.6 percent).[24]

[22] Report of the Senate Special Committee on Science Policy, op. cit., p. 120.

[23] Idem, p. 128.

[24] Idem, p. 132.

Five other factors contribute to Canada's special position among advanced countries. First, public R & D expenditures in this country are the lowest relatively to total government expenditures, among the six OECD members selected by the Senate Committee. Second,

> The Canadian government finances a much lower proportion of extra-mural R & D activities than do most other governments.[25]

Third, a substantial share of government extramural R & D financing is allocated to the academic sector while the industrial sector of most other countries is considerably supported by its government. Fourth, Canadian industry devotes a fairly small proportion of its gross national fixed capital investment to R & D expenditures (2.8 percent in 1967) compared to other advanced nations.[26] Fifth, the number of qualified scientists and engineers (QSE's) in R & D as a proportion of the labor force (.26%) put Canada in third place among leading countries.[27] This high rank is in contrast with other features of the Canadian science picture. This could explain why a surplus of QSE's has been forecasted by the Science Council of Canada.[28] This brief review of the country's R & D picture brings out, among

---

[25] Idem, p. 143.

[26] OECD, R & D in OECD Member Countries: Trends and Objectives, DAS/SPR/70.31, Paris, 17th August, 1970, p. 46.

[27] Report of the Senate Special Committee on Science Policy, op. cit., p. 138.

[28] Kelly, Frank, Prospects for Scientists and Engineers in Canada; Background Study for the Science Council of Canada, Special Study # 20, 1971.

other things, what the Senate Special Committee has called "Canada's special position". The question is whether or not this position reflects the optimum allocation of national scientific resources.

Have the amounts devoted in the past to applied research and especially to development been too limited? If Canadians want to stay in the international technological race, if they want to become masters of their own destiny, if they wish to reap the benefits that can be drawn from innovation, then they should increase their total R & D effort and devote a growing share of these expenditures to development and technology. The United States allocated 3 percent of its GNP to R & D expenditures in 1967 and this represented 67 percent of the ten selected countries' share.[29] Canada should increase her share to at least 2.0 or 2.5 percent of her GNP. Most advanced countries have reached or even passed the 2.0 percent level. The achievement of this objective, however, should depend on the number of scientists and engineers available in this country or from abroad, possessing the relevant qualifications, and also on the number and cost of worthwhile projects that Canada could undertake.

---

[29] Report of the Senate Special Committee on Science Policy, op. cit., p. 122.

Furthermore, Canada's comparative increase of R & D expenditures relatively to other countries should take into account the amount of funds devoted by other nations to defence and space in the scientific field. In a recent study, the OECD has examined government funding of R & D under five principal groups of objectives. Their statistics show that even if government R & D expenditures in defence, civil space and civil nuclear are subtracted from the respective national figures that Canada still ranks low (0.7% of GNP) compared to other advanced countries, especially the United States (1.3% of GNP). Therefore, even though defence expenditures are excluded on the basis of a value judgement, Canada's increase of her national R & D effort is still warranted.

2. The Selection of Fields

The adoption of an adequate science budget and its realistic allocation to the three main categories of R & D activities are not sufficient to ensure an effective national science effort. The second main element of a sound strategy is related to the selection of useful mission-oriented programs.

A rational selection must be based on the best possible knowledge of Canadian needs and capabilities and of programs being carried out in this country and abroad. This could enable a country to meet her national requirements and to develop a strong position on world markets. An efficient and rapid network of information retrieval is even more essential for the planning of applied research and development than it is for the carrying out of an indigenous effort in the area of basic research, because duplication of development work is usually more costly. However, an information network in this area is more difficult to organize and maintain, because this type of R & D activity is often conducted in secret and, when its results are available, they can be obtained more easily through personal contacts than through printed material.

In spite of this difficulty, Canada should try to establish an information service covering applied research and development as complete and efficient as possible. First, such a system would enable Canadians to know better where they stand, where they can go and what resources are available to them.

Second, 98 percent of the world's science and technology is carried on outside Canada; an elaborate international information system represents for this country a warning and monitoring line without which it would be impossible to keep up to date and take advantage of foreign inventions. Third, the knowledge derived from this network could permit domestic industrialists to translate discoveries into technological innovations faster and better than their foreign competitors. The Japanese have exploited international information much to their benefit; yet Canadians who are closer to the main source of practical knowledge (U.S.A.) have failed to do so. Even if new inventions are already protected by a patent, the knowledge that they exist may reduce duplication of research work, offer possibilities of swapping or buying patents and stimulate innovative capabilities. Fourth, this information system would provide engineers and technologists with the latest advances in the new areas of technology. An information network on development activities however cannot be organized along the same lines as a similar service for basic research, which can rely heavily on scientific journals.

Until such a system exists and begins to produce reliable and relatively complete information, it will be difficult to establish priorities for Canada's effort. The government will have to rely considerably on proposals originating from industry and individual inventors who have a detailed knowledge of the needs and opportunities in particular areas. Government science advisors, aware of the importance of the development process in innovations, may also have concrete recommendations to make. They have already put forward certain proposals which show a remarkable consensus of opinion. The OECD report on Canadian science policy has reproduced these suggestions coming from different official sources (see Table 27).

These programs have not been worked out in detail and some of them may not be appropriate for Canada. But at least, they represent a first serious attempt to put forward a plan oriented toward a greater effort in the area of applied research and development. This initiative should be co-ordinated and more refined before Canada is in a position to establish a rational and coherent system of selection. Perhaps a more effective central machinery for science policy formulation might help to improve the decision-making process in this area.

3. The Sectors of Performance

There is a close relationship between the kind of R & D activity to be carried out and the sector of performance which should be responsible for it. The general principle involved here is that research or development should be conducted by the sector which is most likely to use its results and to benefit from its side-effects. This rule originates mainly from the fact that the three major sectors of performance - universities, government and industry - are relatively remote from each other and that the transfer of knowledge from one to the other does not easily occur:

> The link between industry and the university is still extremely small and, in certain cases, non-existent.[30]

Steps could be taken to reduce these solitudes but the three sectors are so differently motivated and organized that they may remain more or less isolated.

Given this fact of life, it would be surprising if the main effort in the area of basic research were to take place in industry. It would seldom reach the universities where it can be used to train new generations of scientists. The same conclusion applies to development operations. When they are expected to produce market-oriented operations, their ideal location is in industry. This requirement of a realistic strategy is generally recognized. Dr. Solandt says:

> I think that research aimed at new products or processes should be as close as possible to the point of use. Usually in industry there have been some striking examples of research on new processes done in government laboratories which have not resulted in any profitable exploitation because they were not done closely enough to the point of use.[31]

Professor Patrick Blackett expressed the same opinion in these words:

---

[30] Dr. Louis Philippe Bonneau, Proceedings of the Senate Special Committee on Science Policy, No. 3, p. 65.

[31] Dr. O.M. Solandt, Proceedings of the Special Committee on Science Policy, op. cit., p. 51.

> Perhaps we have made some mistakes in England by doing a great deal of research and development, but not following it up properly by making the transfer to the manufacturing side of industry. So, to get a realistic return on our money it is necessary to see the whole process right through from the research and development and rough sketches until the project is completed and the product sold profitably.
>
> We are canalizing more and more of our interests towards the latest stages of the innovation chain, whereas in the past we canalized it rather towards the early stages.
>
> If I may say a word about your country, I think you are already facing two of the main problems which face Britain: the problem of transfer of R & D from a government station to manufacturing industry and the selection of firms to receive aid.[32]

It has been shown that government strategy in the past has concentrated its R & D effort in universities and in its own laboratories and that it has relied heavily on the expectation that industry would use the results of that effort for its own benefit. This strategy did not take sufficient account of the rule outlined above.

> NRC staff have been disturbed at the reluctance of industry in Canada to interest itself in NRC's patents and new products ... NRC's designs have consistently high technical merit, but this alone is not enough to warrant commercial support.[33]

In the innovation process production costs and potential sales are equally if not more important than technical merit. Entrepreneurs should be in a better position to appraise

---

[32]Professor P. Blackett, Proceedings of the Senate Special Committee on Science Policy, op. cit., Phase I, p. 91-92.

[33]Proceedings of the Special Committee on Science Policy, op. cit., No. 68 (161) June 9, 1969. p. 8158.

those important variables than government scientists. In addition, industry is better acquainted with its present and future R & D requirements than government laboratories. As a matter of fact, a considerable amount of research in industry is devoted to problem-solving projects[34] of which government laboratories are not aware, or which firms do not care to discuss with them. Brooks confirms this view:

> The existence of a market gives a continuous incentive for self-appraisal, which is often lacking for activities performed in the public sector. When the government supports applied research in an environment that is not organizationally coupled to an end use, it is likely to stray from the mark, and this becomes more of a hazard the closer the research is to application.[35]

A related point made previously needs to be recalled briefly here. Says V.O. Marquez:

> In Canada there is an imbalance. This is perhaps not to say that there is too much effort and money being spent on discovery so much as it is to say that there is too little being devoted to innovation.[36]

If a larger share of a more intense R & D effort is to be devoted to development work and if industry is the ideal location for this type of activity, then private firms in Canada

---

[34] Wilson, A.H., Background to Invention, Background Study for the Science Council of Canada, Special Study No. 11, Queen's Printer for Canada, Ottawa, 1970.

[35] Brooks, H., The Government of Science, op.cit., pp. 296 and 297.

[36] Mr. V.O. Marquez, Proceedings of the Special Committee on Science Policy, No. 68, June 19, 1969, p. 8126.

should become a sector of R & D performance substantially more important than they have been in the past. The government should transfer to that sector a great proportion of the activities which it traditionally carries out in its own laboratories.*

Such an approach has been followed by the most innovative societies, such as the United States, Japan, Sweden and Switzerland. In Canada, figures for the period 1957-1967 show a small 9 percent decrease for the government sector as a source of performance. However, the corresponding gain has been made by universities, not by industry whose share has also declined slightly during the same decade. This trend has not changed since 1967.

Another weakness of the Canadian situation is related to the methods used by the government to fund industrial research. In contrast with other countries such as the U.S.A. and Japan, the Canadian government has not used contract arrangements extensively, except in the field of national defence, and while it has been more generous in providing fiscal incentives, this support does not include the later and more costly stage of the innovative process.

Opinions differ as to the respective merits of these two types of assistance. Some contend that incentives allow too much freedom to industry and not enough control by the government. Others say that contracts may encourage favouritism of large corporations. A mixture of both systems may give the best results. However, the present reluctance to use contractual

*This transfer should consider a change in the present Canadian industrial structure from resource base to manufacturing industries.

arrangements more extensively and to concentrate special incentives on research rather than on development leave the last and most expensive stages of the innovation process largely unassisted. This gap, as Dr. Solandt explains, leads to undesirable results:

> There is the fact that experience both in Canada and in other countries, shows that research done in industry does not pay at all unless it is carried right through to production and use. We have a surprisingly bad record of continuity in this way. We tend to say that we are doing some excellent research and development, that we have produced a prototype of a gadget of some kind; but no one ever builds it, so the money is almost completely wasted.[37]

Nevertheless, the shift from intra-mural government activities to public support for industrial research should not be complete. In general, such a shift should be attempted when market-oriented innovations are involved. But even here, this change may not be possible or desirable, especially when industries are composed of a large number of small enterprises. Agriculture and fisheries operate under such conditions. Moreover, when it comes to areas of purely social innovations or to the development of highly secret weapons, when governments must be the innovators, the public sector can be a better source of performance than either industry or even universities. This R & D area can be illustrated by such fields as health, urban living, poverty and education. Non-profit organizations, other than universities, can also be useful as a sector of performance for these purposes.

---

[37] Dr. O.M. Solandt, Proceedings of the Special Committee on Science Policy; Phase I, March 13, 1968, p. 50.

The main conclusion that can be drawn from the above observations is that Canada should, in her growing R & D expenditures, emphasize her effort on technological innovations; if economic growth is to be promoted, innovations should be made at home to yield their maximum benefits. Canadian industry, being the ideal location for successful development work should become, on its own and through better government support programs, a much stronger sector of R & D performance than it has been in the past.*

4. Scientific and Technological Manpower

In the previous chapter, the necessity of institutional changes in universities has been touched upon as required by the creation of centres of excellence and the multi-disciplinary approach in the area of basic research. This necessity now becomes more evident, if it is decided to increase Canada's total effort substantially and to shift its orientation more decisively toward development work.

In Canada, tradition has emphasized the importance of increasing the output of Ph.D's in pure science. Dr. Steacie even believed that the engineer should receive more or less the same training as the pure scientist:

*Federal funds for industrial R & D activities rests on the assumption that such support would be most favourable to the growth of technological innovations and to general economic conditions. Research should be carried out on this aspect to confirm this assumption.

> There is no reason why an engineering student should ever have seen a plant or a mine before he graduates. "Practical" knowledge can be acquired on the job and is certainly not a proper part of a university education.[38]

The results of these views have been that even in the presentation of Canadian statistics on scientific manpower, the distinction between scientists and engineers has seldom been made. The National Committee of Deans of Engineering and Applied Science complains about this:

> All the statistics dealt with "science and engineering" as if this combination were homogeneous and amenable to the same policy considerations.[39]

The Science Council can also be held responsible for propagating this state of mind in its recent study on "scientists and engineers" in Canada.[40] Only in Appendix B of the study is the distinction made between engineering, physical and life sciences.

In a background study for the Science Council of Canada, Frank Kelly found that an increasing surplus of Ph.D. "scientists and engineers" was likely to occur in the mid-1970's. What the author did not reveal is the employment situation separately for each profession. The only indirect information to that effect is the ratio of scientists to engineers in industry.

---

[38] Babbit, J.D. (editor); Science in Canada, Selection From the Speeches of E.W.R. Steacie; University of Toronto Press, 1965, p. 142.

[39] Proceedings of the Special Committee on Science Policy, No. 56 (115), June 6, 1969, p. 6867.

[40] Kelly, Frank, Prospects for Scientists and Engineers in Canada; op. cit., 1971.

> However, the ratio of scientists to engineers seems rather higher in Canadian industry than in the industry of many other countries.[41]

The failure to make the distinction between scientists and engineers in the evaluation of Canada's R & D personnel can be misleading. It may well be that while the aggregate supply is adequate, its composition is imbalanced. On the one hand, a substantial surplus is being forecast in this area. On the other hand, according to Dr. Solandt, the supply of engineers has ceased to rise:

> One of the most worrying things is the fact that the output of engineers is not growing at all. It really has not changed over the last five or six years, so the percentage of students at universities who are taking engineering is dropping every year.[42]

Commenting on the views it received from industry, the Senate Committee on Science Policy states: "There were specific references to shortages of engineers in several briefs."[43] It also noted numerous complaints that engineers were educated "for an unreal rather than a real world",[44] that they were not sufficiently production oriented, and not interested "in solving the nuts and bolts problems of manufacturing industry today."[45]

---

[41] Idem, p. 20.

[42] Dr. O.M. Solandt, Proceedings of the Special Committee on Science Policy; Phase I, op. cit., p. 49.

[43] Senate Special Committee on Science Policy, op. cit., p. 249.

[44] Idem, p. 247.

[45] Idem, p. 249.

Thus, the problem of the scientific manpower situation in Canada is not only one of surplus of scientists and scarcity of engineers and technologists; it is also, at least insofar as the latter are concerned, a question of quality and appropriate training. If the Canadian situation is not corrected, serious difficulties may arise, as Dr. Alexander King points out:

> Unless, in fact, the educational systems and higher educational systems in their planning are geared to the development of industry and to the possibilities of technology, it is probable that a big unbalance will occur leading to increased brain drains ... and intellectual unemployment in some countries.[46]

The supply of scientific manpower in Canada would already indicate this unbalance and this situation could reach sizeable proportions in the near future, if the proposed shift of a greater R & D effort toward development in industry is attempted. The Canadian government, through the present orientation of its scholarship and fellowship programs, is partly responsible for that situation and should revise substantially its support in this area in order to minimize the surpluses and the scarcities of manpower.

Ultimately, however, universities will be mainly responsible for solving this problem. They may have to change their enrolment practices to correct the imbalance and carry out the qualitative reform which seems to be needed in the training of engineers and technologists for industry.

---

[46] Dr. A. King, Proceedings of the Special Committee on Science Policy; Phase I, op. cit., pp. 272-273.

This chapter has described the main features of development activities and the motivations of technologists who dominate this area of R & D. On the basis of these characteristics, it presents five general proposals that could improve the Canadian science effort by implementing a more efficient strategy designed to produce more inventions and innovations and to create more rapid economic growth and social improvement.

First, the total amount of R & D activities should be increased. Second, the allocation of more resources should be devoted to applied research and development with special emphasis on the latter. Third, most of the performance of applied R & D activities should be shifted from government to industrial laboratories. Fourth, Canadians should develop a faster and more complete international information system to increase efficiency and reduce costs and duplication. Fifth, educational systems and scholarship programs in science and engineering should be adapted to manpower requirements in order to maximize the possibilities of technological innovation. These proposals represent some elements of a new strategy for R & D which could enable Canada to participate more effectively in the international technological race.

CHAPTER IX

SUMMARY AND CONCLUSIONS

Since the end of World War II, especially, the application of scientific and technological knowledge has been recognized as an important determinant of economic growth in advanced countries. Nations have tried to accelerate the rate of growth of that knowledge by the institutionalization of R & D activities. Today, the extension and the effects of these activities have reached such proportions as to merit serious national reviews and assessments.

This thesis was intended to examine R & D operations in Canada, their economic effects, and the factors contributing to them. It also presented specific proposals for a Canadian strategy which would take into account the nature and goals of these activities, the limited resources available to undertake R & D, and the motivations of Canadian scientific and technological personnel in order to maximize economic and social progress.

Research and development are defined, in general terms, as all those activities which contribute to the acquisition of new scientific facts and theories, or which attempt to find different ways of applying knowledge in order to develop new or improved products and processes. These activities are often divided into three categories: basic research aimed primarily at the discovery of new scientific knowledge, applied research which uses basic science for the better understanding of a particular problem or area and development which applies knowledge for the creation of inventions. These definitions exclude explicitely all R & D activities in the social and human sciences, due to the lack of extensive studies on the amount and nature of research carried out in these disciplines.

The measurement of the input and output of R & D activities in most countries is in its infancy and thus still requires conceptual and statistical refinement. In Canada, the Dominion Bureau of Statistics issues an annual publication on government scientific activities and every two years a national inventory. The Science Council is another government agency assessing the Canadian effort in specific areas.

The examination of Canada's total scientific effort over the years shows that it has grown rapidly in importance. In 1967, Canadians spent $895.5 million or 1.4 percent of their GNP on R & D operations and employed 0.7 percent of the total national labor force to carry them out.

Research and development activities are performed and funded by business enterprises, governments, universities and private non-profit organizations. In Canada, all sectors have increased their expenditures in this field but between 1957 and 1967 the government's relative share has tended to decline.

A similar trend has developed in the performance of R & D, and here the main change has been the remarkable gain made by the academic sector. Manpower data over the years indicate that the share of scientific personnel has decreased in industry and risen in universities, while government laboratories steadily maintained their relative position. The distribution of expenditures between the different types of R & D activities and sectors of performance shows that industry performed most of the development, universities most of the fundamental research, while governments and private non-profit organizations engaged mostly in applied research programs. Finally, the concentration of funding within industry and government is considerable in comparison with other sectors which devote only a small share of their budgets to research.

This overall picture of R & D operations in Canada presents distinct contrasts with other advanced countries. First, Canadians held the second last place for the proportion of GNP devoted to national R & D activities. Second, their industry performed the smallest share of these activities as compared with the business sector of other countries and received little assistance from the government especially in contrast with American industry. Third, contrary to most advanced countries, Canada spent relatively large sums for fundamental research in universities and government and comparatively little on development leading to technological innovations. Fourth, the Federal Government performed a high proportion of total R & D and made little use of contractual arrangements with industry. Fifth, the ratio of government R & D expenditures to total government outlays in Canada was the lowest of the six most advanced countries.

From these observations, two important conclusions can be drawn. First, while the Canadian government was offering more generous fiscal incentives to promote R & D in industry than other governments, these programs did not cover the most expensive and potentially profitable activities, namely the last phases of the innovation process. This partly explained why the innovative capacity of Canadian industry remained low.

Second, the role of universities as performers of R & D has been increasing and the relatively large proportion of fundamental research has been carried out mostly in these institutions. This was the result of the views held by pure scientists in universities and government who believed that the new knowledge thus acquired would be automatically transformed by industry into innovations. However, these views ignored how the process of innovation worked and produced a surplus of scientists (especially PhD's) in many areas while engineers, technologists and designers needed by industry were in short supply. As a consequence, graduates coming out of universities to find work in industrial laboratories discovered that they did not possess the necessary practical qualifications. These weaknesses produced a brain drain of pure scientists and the immigration of technologists.

Therefore, both the domestic situation and international comparisons indicate that Canada's past strategies have not been realistic and that the allocation of scientific resources could have been more rational. However, in developing a new approach, two different requirements must be met.

The specific features of the various R & D sectors and activities will have to be better analyzed and recognized than they have been in the past, if science administrators are to be provided with proper guidelines to promote or reduce certain types of R & D in the three main sectors of performance.

The prime motivation of industrial R & D operations is the profitability of technological innovations. The provision by the government of necessary resources and special inducements can stimulate a firm to engage in or increase its research activities. Individual inventors can also contribute to the innovative process given the adequate support and sufficient freedom. His contribution often leads to major inventions and thus more consideration should be given to these special individuals. Governments, universities and other non-profit organizations are motivated by different aims. Contrary to the private sector, public R & D facilities are not profit oriented. They are more likely to be preoccupied with social welfare and the advancement of pure knowledge.

The strategy contributing to the extension and efficiency of R & D activities are therefore closely related to the nature and motivation of each main sector of performance.

Moreover, the analysis contained in this thesis intended to show that an effective strategy must take into account the specific features of different R & D activities.

It was shown that basic research was not a major source of innovations and that it was primarily concerned with the creation of new theoretical knowledge easily accessible as an international free good. These are some of the main reasons why this type of research should not have a high national priority relatively to the total R & D effort. The importance of basic research should not however be underestimated, especially today when the rising social costs of innovations are often due to the lack of understanding of the basic scientific laws involved. The characteristics of fundamental research and the motivation of pure scientists suggest that universities and governments should be the main sectors responsible for the performance of this activity.

Applied research and development activities are mainly oriented towards the creation of new or improved products and processes. They require relatively short periods of time to produce tangible results; they entail smaller market-oriented innovations. The main features suggest that Canada should increase her support of these activities if she wishes to remain in the technological race, to maintain the rate of her economic progress and increase her national identity. Furthermore the characteristics of development activities, including the motivation of technologists, indicate that they should be conducted by the sector which is most likely to use their results. This requirement shows that their ideal location is in industry rather than in government or university laboratories. Finally development work in Canadian industry must be encouraged by the government in its support of the last stage of the innovation process and it should be accompanied by a better balanced supply of scientific manpower to meet industrial requirements.

These considerations on a strategy for Canada represent only a first step towards the elaboration of a new approach to science policy. It will not be completed until more Canadian studies become available on the nature of R & D activities and the process of technological innovation.

In developing a new approach aimed at producing more innovations, it will be necessary to consider the total economic and social consequences of technological change much more carefully than most countries have done up to now. These effects of R & D leading to innovations can be positive, negative or both. They can be beneficial to some people and harmful to others; they can be good in the immediate and bad in the long run.

Firms which successfully engage in the creation of new or improved products and processes can increase their profits, their power on the market and protect themselves from technological obsolescence as well as from domestic or foreign competitors. Society as a whole and its members may also benefit from R & D activities through the creation of new employment, a better and wide variety of choice of goods and services, an overall increase in productivity, the standard of living, leisure time and of the life span.

But the application of scientific and technological knowledge may also have unfavourable consequences such as the pollution of the environment, unemployment, waste of resources, loss of consumer sovereignty, alienation and the scarcity of time. In the past, society has neglected to consider these negative aspects. This oversight, if not corrected, may lead to uncontrolable and irreversable situations.

Fortunately, the awareness of these economic and social costs has been growing recently and greater efforts are being made to minimize them. The innovator of the future will have to face the difficult task of tackling both the positive and the negative economic and social effects of his innovations. Society will not be able to rely exclusively on professional and community involvement. Governments will have to develop effective assessment and planning tools to assure that the benefits of innovations are maximized and their costs minimized. This aspect of scientific strategy will have to be given more attention in the future.

APPENDIX A

TABULAR MATERIAL

TABLE 1. TOTAL GROSS EXPENDITURES ON R & D (GERD) AND GROSS NATIONAL PRODUCT IN CURRENT DOLLARS, CANADA, 1957-1967.

	GNP (Million $)	GERD (Million $)	Percent of GNP
1957	32,907	304.6	1.9
1958	34,094	329.1	1.0
1959	36,266	309.2	0.8
1960	37,775	321.7	0.8
1961	39,080	392.8	1.0
1962	42,353	403.9	0.9
1963	45,465	464.4	1.0
1964	49,783	561.4	1.1
1965	54,897	676.6	1.2
1966	61,421	769.2	1.2
1967	65,608	895.5	1.4

Source: GNP figures obtained from revised tables in National Income and Expenditure Accounts 1926-1968, D.B.S., August, 1969, p. 6.

GERD from tables supplied by R.W. Jackson, Science Council.

TABLE 2. TOTAL GROSS EXPENDITURES ON R & D (GERD) AND GROSS NATIONAL PRODUCT IN CONSTANT DOLLARS, CANADA, 1957-1967.

	Million $	
Year	GNP	GERD
1957	34,710	321.0
1958	35,462	341.6
1959	36,929	314.8
1960	37,994	323.3
1961	39,080	392.8
1962	41,778	398.2
1963	43,996	449.2
1964	47,050	530.5
1965	50,149	621.4
1966	53,650	670.5
1967	55,407	755.8
	ANNUAL PERCENT INCREASE	
1957	-	-
1958	2.1	6.4
1959	3.8	7.8
1960	2.8	6.0
1961	2.8	21.6
1962	6.8	1.2
1963	5.4	12.8
1964	9.2	20.4
1965	6.5	17.0
1966	6.9	8.0
1967	3.2	12.8
Average 1957-1967	4.9	9.8

Source: GNP figures from revised tables in National Income and Expenditure Accounts 1926-1968, D.B.S. August, 1969, pp. 34-35.

GERD figures calculated from previous table with implicit price deflator for GNE, based on 1961.

TABLE 3. TOTAL MANPOWER ENGAGED IN R & D, CANADA, 1963, 1965 AND 1967

Personnel	Employment in R&D Number (,000)	Percent	Total Employment millions	R&D Staff as Percent of Total Employment
Total 1963	31.7	100.0	6,375	0.5
Scien. and engineers	11.5	36.2		
Technicians	10.8	34.1		
Supporting personnel	9.4	29.7		
Total 1965	40.7	100.0	6,861	0.6
Scien. and engineers	15.1	37.1		
Technicians	14.5	35.6		
Supporting personnel	11.1	27.3		
Total 1967	51.8	100.0	7,379	0.7
Scien. and engineers	19.3	37.2		
Technicians	18.5	35.7		
Supporting personnel	14.0	27.1		

Source: Numbers of people employed were obtained from D.B.S. Catalogue 13-532: Industrial Research and Development Expenditures in Canada, 1967; p. 62. Total national employment figures originate from Canada Year Book 1968, p. 756.

TABLE 4. DISTRIBUTION OF NATIONAL R & D EXPENDITURES, BY SOURCE OF FUNDS, CANADA, 1957-1967.

	Government	Industry	Universities	Other	Total
			Million $		
1957	208.3	78.6	14.6	3.1	304.6
1958	198.3	105.2	19.3	6.0	329.1
1959	183.5	93.9	25.0	6.8	309.2
1960	205.0	77.5	30.9	8.3	321.7
1961	234.7	117.0	31.6	9.5	392.8
1962	230.7	122.6	38.0	12.6	403.9
1963	246.4	153.7	45.9	18.4	464.4
1964	288.5	187.9	60.2	24.8	561.4
1965	345.8	214.9	77.2	38.7	676.6
1966	409.1	215.2	101.4	43.5	769.2
1967[1]....	478.3	277.7	107.9	31.7	895.5
			P E R C E N T		
1957	68.4	25.8	4.8	1.0	100.0
1958	60.3	32.0	5.9	1.8	100.0
1959	59.3	30.4	8.1	2.2	100.0
1960	63.7	24.1	9.6	2.6	100.0
1961	59.8	29.8	8.0	2.4	100.0
1962	57.1	30.4	9.4	3.1	100.0
1963	53.1	33.1	9.9	4.0	100.0
1964	51.4	33.5	10.7	4.4	100.0
1965	51.1	31.8	11.4	5.7	100.0
1966	53.2	28.0	13.2	5.7	100.0
1967	53.4	31.0	12.0	3.5	100.0

Source: Data for 1957-1966, supplied by Science Council of Canada. Data for 1967 by courtesy of D.B.S.

Note: Figures may not add to totals shown because of rounding.

TABLE 5. DISTRIBUTION OF NATIONAL R & D EXPENDITURES BY SECTOR OF PERFORMANCE, CANADA, 1957-1967.

	Government	Industry	Universities	Other	Total
			Million $		
1957	134.9	140.1	25.8	3.8	304.6
1958	141.0	150.5	33.8	3.8	329.1
1959	151.2	110.3	43.3	4.3	309.2
1960	172.4	92.7	51.8	4.8	321.7
1961	199.0	130.5	57.8	5.5	392.8
1962	187.9	140.3	69.6	6.1	403.9
1963	187.7	184.3	85.2	7.2	464.4
1964	207.5	237.9	108.4	7.6	561.4
1965	234.6	287.9	146.2	7.9	676.6
1966	266.6	303.2	189.4	10.0	769.2
1967[1]....	318.9	337.8	238.8		895.5
			P E R C E N T		
1957	44.3	46.0	8.5	1.2	100.0
1958	42.8	45.7	10.3	1.2	100.0
1959	48.9	35.7	14.0	1.4	100.0
1960	53.6	28.8	16.1	1.5	100.0
1961	50.7	33.2	14.7	1.4	100.0
1962	46.5	34.7	17.2	1.5	100.0
1963	40.4	39.7	18.3	1.6	100.0
1964	37.0	42.4	19.3	1.4	100.0
1965	34.7	42.6	21.6	1.2	100.0
1966	34.7	39.4	24.6	1.3	100.0
1967	35.6	37.7	26.7		100.0

Source: Data for 1957-1966 supplied by Science Council of Canada. Data for 1967 by courtesy of D.B.S.

Note: Figures may not add to totals shown because of rounding.

TABLE 6. TOTAL MANPOWER ENGAGED IN R & D, CANADA, 1963, 1965 AND 1967.

Sources of funds	Performance Sectors -Thousands-			
	Business Enterprises	General Government	Higher Education Private Non-Profit	Total
1963				
Scien.-eng.	5.8	3.5	2.2	11.5
Technicians	4.7	3.6	2.5	20.2
Supp. pers.	3.7	5.7	-	(10.8)
Total	14.2	12.8	4.7	31.7
1965				
Scien.-eng.	6.4	4.7	4.0	15.1
Technicians	5.6	4.7	4.2	25.6
Supp. pers.	3.8	7.3	-	(14.5)
Total	15.8	16.7	8.2	40.7
1967				
Scien.-eng.	7.5	5.9	5.9	19.3
Technicians	6.4	6.2	5.9	32.5
Supp. pers.	4.8	9.1	-	(18.5)
Total	18.7	21.2	11.8	51.8
PERCENT				
1963				
Scien.-eng.	50.0	30.0	20.0	100.0
Technicians	44.0	33.0	23.0	100.0
Supp. pers.	39.0	61.0	-	100.0
Total	45.0	41.0	14.0	100.0
1965				
Scien.-eng.	43.0	31.0	26.0	100.0
Technicians	39.0	32.0	29.0	100.0
Supp. pers.	34.0	66.0	-	100.0
Total	38.0	41.0	21.0	100.0
1967				
Scien.-eng.	38.0	31.0	31.0	100.0
Technicians	35.0	34.0	31.0	100.0
Supp. pers.	34.0	66.0	-	100.0
Total	36.0	41.0	23.0	100.0

Source: Data for the number of R & D personnel, obtained from D.B.S.: Catalogue 13-532, Industrial R & D Expenditures in Canada, 1967, p. 62.

Note: Figures in parenthesis obtained by substracting from total.

TABLE 7. CURRENT RESEARCH AND DEVELOPMENT EXPENDITURES BY TYPE OF RESEARCH AND RESEARCH BODY, CANADA, 1965

	Fundamental Research	Applied Research	Development	Total
	Million $			
Industry	8.9	65.0	160.2	234.1
Government	37.8	121.2	29.5	188.5
Higher Education	70.0	25.0	5.0	100.0
Non-Profit Institutions	1.7	4.3	0.7	6.7
Total	118.4	215.5	195.4	529.3
	Percent			
Industry	3.8	27.8	68.4	100.0
Government	20.0	64.4	15.6	100.0
Higher Education	70.0	25.0	5.0	100.0
Non-Profit Institutions	25.4	64.2	10.4	100.0
Total	22.4	40.7	36.9	100.0

Source: Absolute figures obtained from a report on *Industrial R & D in Canada* to the Science Council of Canada at its meeting on March 17, 1967, presented by Mr. J.L. Orr, Industrial Research Adviser, Department of Industry.

TABLE 8. FOREIGN SOURCES OF FUNDS, BY PERFORMANCE SECTORS, CANADA, 1963-1967.

	Performance Sectors			
Sources of Funds	Business Enterprises	General Government	Higher Education Private non-profit	Total
1963	Million $			
Foreign	7	0	5	13
Canadian	174	188	72	434
Total	181	188	77	447
1965				
Foreign	26	1	7	34
Canadian	261	243	136	641
Total	287	244	143	675
1967				
Foreign	17	3	4	25
Canadian	321	315	235	871
Total	338	318	239	896
	Percent			
1963				
Foreign	4.0	0	6.9	2.8
Canadian	96.0	100	93.1	97.3
Total	100.0	100.0	100.0	100.0
1965				
Foreign	9.9	0	5.1	5.3
Canadian	91.1	100	94.9	94.7
Total	100.0	100.0	100.0	100.0
1967				
Foreign	5.2	1.0	1.7	2.9
Canadian	94.8	99.0	98.3	97.1
Total	100.0	100.0	100.0	100.0

Source: Absolute figures were obtained from D.B.S. Catalogue 13-532; Industrial Research and Development Expenditures in Canada, 1967, p. 62.

TABLE 9. INDUSTRIAL R & D EXPENDITURES, CANADA, 1957-1967.

Year	Number of Reporting Companies	Current intra-mural	Capital	Total intra-mural	Net Canadian extra-mural	Total in Canada	Foreign extra-mural	Total
		Expenditures Million $						
1957	455	124.5	12.6	137.1	4.2	141.3	19.8	161.1
1959	471	96.6	10.7	107.3	3.3	110.6	21.7	132.3
1961	523	114.0	13.5	127.5	1.9	129.4	31.2	160.6
1963	701	153.1	27.4	180.5	3.3	183.8	26.9	210.7
1965	825	234.1	49.8	283.9	3.1	287.0	27.1	314.1
1967	849	292.9	44.8	337.8	3.2	341.1	34.5	375.6
		Percent						
1957		77.0	9.0	85.0	2.8	87.8	12.2	100
1959		73.4	7.6	81.0	3.0	84.0	16.0	100
1961		71.3	8.7	80.0	0.6	80.6	19.4	100
1963		72.5	13.2	85.7	1.6	87.2	12.8	100
1965		77.9	12.5	90.4	1.0	91.4	8.6	100
1967		77.9	11.9	89.8	0.8	90.6	9.4	100

Source: Absolute figures were obtained from J.L. Orr, Industrial Research Adviser, Department of Industry, Ottawa, Statistical Data on Industrial Research and Development in Canada: Report to the Science Council of Canada at its meeting on March 17, 1967. Absolute figures for 1967 were obtained from D.B.S. publication 13-532: Industrial Research and Development Expenditures in Canada, 1967.

TABLE 10. TOTAL INTRAMURAL R & D EXPENDITURES, BY INDUSTRY, CANADA, 1963-1967.

Industry	1963	1964	1965	1966	1967	1968
	Million $					
Mines	5.5	7.5	7.5	9.2	10.7	9.8
Gas and oil wells	0.9	1.8	1.6	2.9	3.3	3.4
Manufacturing						
Food and beverages	4.9	5.8	6.6	9.1	8.9	10.3
Rubber	2.0	2.4	2.8	3.3	3.9	4.2
Textiles	2.6	3.2	4.2	4.9	4.0	4.4
Wood	0.2	0.2	0.4	0.4	1.3	0.7
Furniture and fixtures	0.1	0.1	0.1	0.1	0.2	0.2
Paper	15.1	20.4	26.6	27.7	26.1	24.8
Primary metals (ferrous)	3.7	7.0	7.6	8.7	6.2	6.3
Primary metals (non-ferrous)	11.9	11.7	13.8	16.6	20.1	16.2
Metal fabricating	1.9	2.0	2.5	3.1	4.9	5.8
Machinery	6.8	8.1	8.6	11.2	13.8	15.3
Aircraft and parts	32.9	43.4	57.5	50.5	40.9	43.7
Other transportation equipment	0.8	1.7	2.2	2.4	3.6	3.8
Electrical products	39.2	50.5	65.1	76.9	94.7	93.7
Non-metallic mineral products	2.1	2.0	1.8	2.8	3.3	3.3
Petroleum products	11.2	10.0	22.5	19.3	21.5	27.7
Drugs and medicines	5.5	7.1	9.3	9.3	10.5	11.4
Other chemical products	21.4	27.8	30.6	36.0	36.5	32.9
Scientific and professional instruments	5.7	5.7	7.5	10.3	9.2	9.9
Other manufacturing	1.2	1.3	1.8	3.7	3.1	3.0
Manufacturing - Total	169.3	210.6	271.5	296.3	312.7	317.7
Transportation and other utilities	3.2	3.9	3.6	4.3	5.5	10.7
Other non-manufacturing	1.6	3.2	3.0	4.5	5.6	5.1
Total	180.4	227.0	287.4	317.1	337.8	346.6
Annual change %	31	26	27	10	6	3

Source: D.B.S. Catalogue # 13-532: Industrial Research and Development Expenditures in Canada, 1967, p. 30.

Note: 1963 to 1966 are revised figures.
1968 are preliminary figures.

TABLE 11. CONCENTRATION OF TOTAL CURRENT INTRA-MURAL EXPENDITURES IN INDUSTRY, CANADA, 1963-1968.

Industry	1963	1964	1965	1966	1967	1968
			percent			
Electrical products	21	22	24	26	28	28
Aircraft	21	23	24	19	14	14
Chemical Products	14	14	13	13	14	13
Three Industries	56	59	61	58	56	55
			percent			
Primary metals	8	7	7	6	7	6
Paper	7	8	6	7	6	6
Petroleum Products	5	5	5	5	6	6
Other	24	21	21	24	25	26
Total	100	100	100	100	100	100

Source: D.B.S. Catalogue # 13-532: Industrial Research and Development Expenditures in Canada, 1967, p. 20.

TABLE 12. SOURCES OF FUNDS FOR INTRAMURAL R & D, CANADA, 1957-1967.

Source	1957	1959	1961	1963	1965	1967
			percent			
Reporting Company	39.1	65.7	69.8	77.5	70.8	77.0
Related Company	7.3	10.1	7.3	1.7	1.2	2.0
Government	49.4	21.8	16.0	18.4	17.3	14.0
Other Companies	4.2	2.4	4.8	1.1	3.7	3.0
Others	-	-	2.1	1.3	7.0	4.0
Total	100	100	100	100	100	100

Source: Obtained from absolute figures in D.B.S. Catalogue # 13-520, 13-524, 13-527, 13-532: Industrial Research and Development Expenditures in Canada, 1961, 1963, 1965, 1967.

TABLE 13. DISTRIBUTION AND CONCENTRATION OF GOVERNMENT FUNDS AMONG INDUSTRIES FOR INTRAMURAL R & D, CANADA, 1957-1967.

Industry	1957	1959	1961	1963	1965	1967
			percent			
Transportation Equipment	94.1	69.0	37.3	48.6	51.8	40.1
Aircraft and parts	-	-	-	-	51.8	40.0
Electrical Products	4.7	30.0	52.2	33.3	30.8	35.2
Scientific and Professional instruments ...	-	-	-	-	5.9	5.8
Manufacturing - Total	99.4	99.8	99.5	99.1	99.2	97.0
Total	100	100	100	100	100	100

Source: Obtained from absolute figures in D.B.S. Catalogue # 13-520, 13-524, 13-527, 13-532: Industrial Research and Development Expenditures in Canada, 1961, 1963, 1965, 1967.

TABLE 14. R & D PERSONNEL, BY CATEGORY AND INDUSTRY, CANADA, 1967

Industry	Scientists and Engineers			Supporting Personnel			Total
	Bachelors	Masters	Doctors	Tech.	Other	Total	
	Full-time equivalent						
Electrical Products	1,652	278	91	1,973	1,309	3,282	5,303
Chemical Products	926	170	325	1,077	498	1,575	2,996
Aircraft and Parts	643	87	11	728	821	1,549	2,290
Primary Metals	291	81	130	486	317	803	1,305
Paper	310	64	114	533	309	842	1,330
Total Manufacturing	5,092	902	896	6,075	4,509	10,584	17,474
Total - All industries ...	5,499	995	973	6,457	4,777	11,234	18,701

Source: D.B.S. Catalogue # 13-532, Industrial Research and Development Expenditures in Canada, 1967, p. 44.

TABLE 15. FEDERAL GOVERNMENT CURRENT EXPENDITURES ON R & D, BY PERFORMANCE SECTORS, CANADA, 1963-64 to 1967-68.

Performance Sector	1963-64	1964-65	1965-66	1966-67	1967-68
Federal Government	71	67	61	63	58
Industry	17	19	23	18	21
Universities and non-profit institutions ..	11	13	15	17	17
Others[1]	1	1	1	2	4
Total	100	100	100	100	100

Source: Percent figures for 1963-64 to 1967-68 obtained from OECD: Review of National Science Policy; Paris, 1969, p. 98. Absolute data originating from D.B.S. Catalogue # 13-401: Federal Government Expenditures on Scientific Activities, Fiscal Year 1967-68; p. 10.

Note: [1]"Others" include provincial governments and foreign recipients.

TABLE 16. FEDERAL GOVERNMENT CURRENT EXPENDITURE ON INTRAMURAL RESEARCH AND DEVELOPMENT, CANADA, 1958-59 to 1967-68.

Percent

Department or Agency	1958-59	1960-61	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68
Agriculture	22.9	19.6	18.7	17.3	17.4	17.0	16.4	14.9
Atomic Energy of Canada Ltd...	18.1	16.0	18.4	19.2	20.1	20.1	20.6	21.0
Energy, Mines and Resources...	6.8	9.0	8.8	10.1	10.3	10.5	10.2	10.6
Fisheries	5.0	4.7	5.8	5.5	5.9	6.1	6.5	6.5
Forestry and rural Development	2.6	6.9	5.3	5.1	4.6	4.5	5.0	5.4
Indian Affairs and Northern Development	0.7	0.7	0.5	0.5	0.5	0.5	0.7	1.0
National Defence	23.7	23.8	20.7	22.1	20.5	19.8	18.3	18.5
National Health and Welfare	1.1	1.3	1.3	1.2	1.3	1.3	1.3	1.6
National Research Council	17.9	15.9	17.9	16.9	16.9	17.8	18.7	18.1
Transport	0.9	0.9	1.6	1.1	1.4	1.4	1.1	1.4
Others	0.3	1.2	1.0	1.2	1.1	1.0	1.0	1.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Percent figures obtained from OECD: Reviews of National Science Policy: Canada, Paris 1969. Original source of absolute figures are published in D.B.S. Catalogue 13-401: Federal Government Expenditures on Scientific Activities, Fiscal Year 1966-67. Figures for 1967-68 were calculated from D.B.S. estimates.

Notes: [1]Fiscal year ending March 31st.

[2]Some departments have been reorganized over the years. When scientific branches have been relocated, the estimates for earlier years have been adjusted. The data in this table are therefore arranged as if the present departmental organization has existed since 1958-59.

[3]Totals may not add exactly because of rounding.

TABLE 17. CURRENT INTRAMURAL EXPENDITURES OF THE FEDERAL GOVERNMENT BY CATEGORY OF R & D, CANADA, 1967-68[1]

Department or Agency	Basic Research	Applied Research	Development	Total
	Million $			
AEC	10.4	33.1	5.9	49.4
NRC	21.1	19.3	3.8	44.2
National Defence	10.0	13.4	15.3	38.7
Agriculture	3.6	28.7	3.5	35.8
EMR	10.3	11.7	5.5	27.5
Others	2.6	26.3	10.5	40.4
Total	58.0	132.4	44.5	235.0
	Percent			
AEC	21	67	12	100
NRC	49	43	8	100
National Defence	27	34	39	100
Agriculture	11	80	10	100
EMR	41	42	17	100
Others	9	65	26	100
Total	24	56	20	100

Source: Absolute figures were obtained from D.B.S. Catalogue # 13-302: Federal Government Expenditures on Scientific Activities; Fiscal Year 1967-68, p. 34.

Note: Fiscal Year ending March 31st.

TABLE 18. FEDERAL GOVERNMENT MANPOWER EMPLOYED IN INTRAMURAL RESEARCH AND DEVELOPMENT, CANADA, 1967[1]

Department or Agency	Scientists and Engineers				Supporting Personnel			Total
	Bachelors	Masters	Doctors	Total	Technicians	Other	Total	
	Numbers (2)							
Agriculture	134	220	551	905	629	1,620	2,249	3,154
Atomic Energy of Canada Limited ..	364	104	162	630	700	1,854	2,554	3,184
Energy, Mines and Resources	324	122	285	731	508	448	956	1,687
Fisheries	151	82	103	336	355	272	627	963
Forestry and Rural Development ...	71	130	188	389	551	268	819	1,208
Indian Affairs and Northern Development	9	37	23	69	23	36	59	128
National Defence	237	192	179	608	839	1,271	2,110	2,718
National Health and Welfare	83	32	89	204	139	57	196	400
National Research Council	145	164	424	733	757	1,209	1,966	2,699
Transport	42	39	7	88	75	14	89	177
Veterans Affairs	8	14	8	30	34	4	38	68
Others	26	7	14	47	45	16	61	108
Total	1,594	1,143	2,033	4,770	4,655	7,069	11,724	16,494
(Total as of 31 March 1966)	(1,407)	(1,098)	(1,900)	(4,305)			(10,792)	(15,0

Source: Dominion Bureau of Statistics, Federal Government Expenditures on Scientific Activities, Fiscal Year 1966-67, p. 37.

Notes: [1]Covers fiscal year ending March 31st. Data relate to permanent staff only. During 1966-67, an estimated full-time equivalent of 164 scientists or engineers and 1,116 supporting personnel were also engaged, on a casual or seasonal basis, on intramural research and development.

[2]Full-time equivalents.

TABLE 19. TOTAL EXPENDITURES ON R & D, BY PROVINCIAL RESEARCH COUNCILS AND FOUNDATION, CANADA, 1963-68

Expenditures	1963	1964	1965	1966	1967	1968
	Million $					
Intramural expenditure						
Current						
Wages and salaries	3.1	3.6	4.2	4.7	5.3	5.8
Other	2.2	2.5	2.8	3.3	3.6	4.2
Sub-totals	5.3	6.1	7.0	8.0	8.9	10.0
Capital						
Land and buildings	0.7	0.3	2.3	4.2	4.3	4.2
Equipment	0.3	0.4	0.6	0.8	1.2	1.7
Sub-totals	1.0	0.7	2.9	5.0	5.5	5.9
Intramural - Total	6.3	6.8	9.9	13.0	14.4	15.9
Extramural expenditures	0.2	0.2	0.1	0.1	0.1	0.1
Total	6.5	7.0	10.0	13.1	14.5	16.0

Source: D.B.S. Catalogue # 13-532: Industrial Research and Development in Canada, 1967, p. 55.

TABLE 20. RESEARCH IN SCIENCE AND ENGINEERING IN UNIVERSITIES, RESEARCH FUNDS SPENT, CANADA, 1955-56, 1964-65[1]

Year	Operating and Minor Equipment(2)	Total Funds Spent for Research(2) (3)
	Million $	
1955-56	7.3	8.0
1956-57	8.9	11.8
1957-58	10.7	14.3
1958-59	13.7	18.6
1959-60	18.0	24.7
1960-61	20.7	30.7
1961-62	24.4	29.8
1962-63	29.7	38.7
1963-64	33.4	46.0
1964-65	39.5	61.4

Source: National Research Council; Expenditures on Research in Science and Engineering at Canadian Universities, No. 9196, September, 1966, p. 30.

Notes: [1]Medical schools excluded.

[2]Includes funds allocated for research and the university contribution.

[3]Includes funds for major equipment, major installations and construction for research.

TABLE 21. RESEARCH IN SCIENCE AND ENGINEERING IN UNIVERSITIES, RESEARCH FUNDS FOR OPERATING AND CAPITAL EXPENDITURES, CANADA, 1964-65.

Source	Percent of Total Funds
Federal Government	26.8
Provincial	8.2
Canadian University Funds	54.7
Total - All Canadian Sources	94.7
Total - Non-Canadian Sources	5.3
Grand Total	100.0

Source: National Research Council; Expenditures on Research in Science and Engineering at Canadian Universities; No. 9196, September, 1966, p. 34.

TABLE 22. SOURCES OF R & D FUNDS FOR PRIVATE NON-PROFIT ORGANIZATIONS, CANADA, 1965

Source[1]	Recipients					
	Foundations	Hospitals	Scientific and Technical Societies	Semi-Provincial Government Organizations	Voluntary Health Organizations	Total
	Thousand $[2]					
Non-profit organizations	482	4,126	162	-	414	(3)
Federal Government ...	-	1,753	247	790	353	3,143
Provincial Governments	-	788	150	1,166	216	2,320
Industry	-	126	328	-	123	577
Individuals	-	196	221	34	5,093	5,544
Foreign sources	-	756	2	-	-	758
Total	482	7,745	1,110	1,990	6,199	(3)

[1]Reported by recipient.

[2]Although amounts are given to the nearest thousand, it must not be assumed that the date are accurate to the nearest thousand.

[3]Since some funds are re-distributed within the sector, it would not be correct to total these rows.

Source: D.B.S. Catalogue # 13-526: Expenditures on Scientific Activities by Non-Profit Organizations, 1965.

TABLE 23. PERCENTAGE OF GNP DEVOTED TO GERD, R & D EXPENDITURES ($US) AND R & D MANPOWER (QUALIFIED SCIENTISTS AND ENGINEERS, QSE) FOR TEN SELECTED OECD COUNTRIES.

	GERD/GNP[1]		R & D Expenditures[1] Millions of US$ 1967		R & D Manpower[1] QSEs in R & D 1967	
Country	1963	1967	Amount of $	% Share	Number	% Share
USA (1964-66) ...	3.0	2.9	22,285	67.0	537,278	58.6
U.K. (1964)	2.3	2.3	2,533	7.6	50,350	5.5
France	1.6	2.3	2,507	7.5	49,224	5.4
Netherlands (1964)	1.9	2.3	514	1.5	15,700	1.7
Switzerland	-	1.9	304	0.9	10,954	1.2
Germany (1964) ..	1.4	1.7	2,084	6.3	61,059	6.7
Japan	1.5	1.8[2]	1,684	5.1	157,612	17.2
Sweden (1964) ...	1.3	1.4	336	1.0	7,395	0.8
Canada	1.1	1.4[3]	828	2.5	19,350	2.1
Belgium	1.0	0.9	176	0.5	7,945	0.9
Total			33,251	100.00	917,357	100.00

Sources: Data obtained from OECD Document DAS/SPR/70.48, Table I, 1970.

Notes: [1]OECD, 1970, Document DAS/SPR/70.48, Table I.

[2]Japan Science and Technology Agency, <u>Summary White Paper of Science and Technology</u>, March, 1969.

[3]Based on revised tables of <u>National Income and Expenditures</u>.

TABLE 24. DISTRIBUTION OF TOTAL NATIONAL R & D EXPENDITURES BY TYPE OF ACTIVITY AND COUNTRY, 1967.

	Percent[1]		
Country	Development	Applied Research	Fundamental Research
Switzerland[2]	3	3	14.5
U.K.	64.6	24.4	11.0
U.S.A.	64.3	21.6	14.1
Netherlands	48.7	3	3
France	47.8	3	3
Japan	42.5	30.8	26.7
Canada	38.9	38.0	23.1
Belgium	37.2	42.2	20.5

Source: Report of the Senate Special Committee on Science Policy; A Science Policy for Canada: Volume I, Ottawa, 1970, p. 125.

Notes: [1]OECD Document DAS/SPR/70.48, Table V.

[2]Courtesy Swiss Embassy, Washington, D.C.

[3]No breakdown available between categories of R & D.

TABLE 25. DISTRIBUTION OF NATIONAL R & D EXPENDITURES BY SECTORS OF PERFORMANCE AND COUNTRY, 1967.

	Percent			
Country	Business Enterprise	Government	Higher Education	Private Non-Profit
Switzerland	76.5	6.3	17.1	-
Sweden	69.9	14.2	15.5	0.4
U.S.A.	69.8	14.5	12.2	3.6
Germany	68.2	5.1	16.3	10.4
Belgium	66.8	10.4	21.4	1.3
U.K.	64.9	24.8	7.8	2.5
Japan	62.5	13.0	22.9	1.6
Netherlands	58.1	2.7	17.7	21.5
France	54.2	32.1	12.9	0.8
Canada	37.7	35.6	26.7	

Source: Report of the Senate Special Committee on Science Policy; A Science Policy for Canada: Volume I, Ottawa, 1970, p. 124.

Note: OECD, Document DAS/SPR/70.48, Table IV.

TABLE 26. DISTRIBUTION OF NATIONAL R & D EXPENDITURES BY SOURCE OF FUNDING AND COUNTRY, 1967.

Country	Business Enterprise	Govern-ment	Private Non-Profit	Higher Education	Abroad
			Percent[1]		
Switzerland	78.1	21.1	-	0.8	-
Japan	62.8	30.2	0.8	6.1	0.1
Belgium	61.2	18.8	3.7	12.6	3.7
Germany	57.5	41.3	0.7	-	0.5
Netherlands	57.5	39.0	1.8	0.1	1.9
Sweden	55.1	42.1	1.7	0.2	1.0
U.K.	42.1	51.3	2.9	0.6	3.1
U.S.A.	32.8	62.7	1.4	3.0	-
France	31.8	64.9	(2)	(3)	3.3
Canada	31.0	53.4	0.8	12.0	2.8

Source: Report of the Senate Special Committee on Science Policy; A Science Policy for Canada; Volume I, Ottawa, 1970, p. 128.

Notes: [1]OECD Document DAS/SPR/70.48, Table III.

[2]Included in Business Enterprise.

[3]Included in Government.

TABLE 27. FEDERAL GOVERNMENT R & D EXPENDITURES AS A PERCENTAGE OF ALL GOVERNMENT EXPENDITURES, BY COUNTRY, FOR SPECIFIED YEARS

	1959	1961	1963	1965	1967
United States	5.9	6.0	6.5	6.6	5.7
France	2.2	2.6	2.8	3.6	3.9
Japan	2.7[1]	3.0	3.0	3.7	3.5
United Kingdom	-	4.2	-	3.4[2]	3.1
Germany	-	1.7	2.0	2.3	2.4
Canada	1.8	-	1.8	2.1	2.3

Source: OECD Document, DAS/SPR/70.31, August 17, 1970

Notes: [1]1960

[2]1964

- means not available

TABLE 28. QUALIFIED SCIENTISTS AND ENGINEERS (QSE's) IN R & D IN SEVEN OECD COUNTRIES, 1967

Country	Total No. of QSEs in R & D	Total Civilian Labour Force Employed (000's)	QSEs in R & D as percent of Labour Force	Rank
U.S.A.	537,273	74,373	0.72	1
France	49,224	10,620	0.46	2
Canada	19,350	7,379	0.26	3
Germany	61,559	25,803	0.24	4
Belgium	7,945	3,616	0.22	5
U.K.	50,345	24,509	0.21	6
Sweden	7,395	3,734	0.20	7

Source of the number of QSE's from OECD Document DAS/SPR/70.48, Table VIII, 1970, and total civilian labor force employed from International Labour Office, <u>Year Book of Labor Statistics</u>, 1969, pp. 292-312.

TABLE 29. PERCENTAGE PATENTS ISSUED TO RESIDENTS OF CANADA BY INDEPENDENT INVENTORS AND CORPORATIONS, 1908-1968.

	Percentage of Patents Issued to:	
	Independent Inventors	Corporations
1908	97.3	2.7
1918	93.2	6.8
1928	82.2	17.8
1938	82.5	17.5
1948	65.0	35.0
1958	50.0	50.0
1968	36.5	63.5

Source: Estimates based on data in the _Canadian Patent Office Record_ for the years noted.

O.M. Solandt Chairman of the Science Council	W.G. Schneider Chairman of the National Research Council
Communications Industrial productivity: - automation - processes - management Transport Urban development Development of the Northern Regions Techniques suitable for cold climate Aid to developing countries	Timber, pulp and paper Metal - specialisation Development of the Northern Regions Transport Energy Electronics Education: - techniques - instruments Chemicals Communications Satellites Urban development and ekistics
Science Secretariat Special Study No. 4	**Science Council Report No. 4**
Information transfer Space Electrical energy Transport ING and TRIUMF[1] Materials Foodstuffs Fuel Biology and biomedical engineering Environment: - urban - development of the Northern Regions - undersea exploration	Space Water resources management and development Transportation Urban development Computer applications Scientific and technological aid to developing areas of the world

Source: OECD, Review of National Science Policy: Canada, Paris, 1969, p. 270.

Note: [1]ING: Intense Neutron Generator
TRIUMF: Tri-University Meson Facility

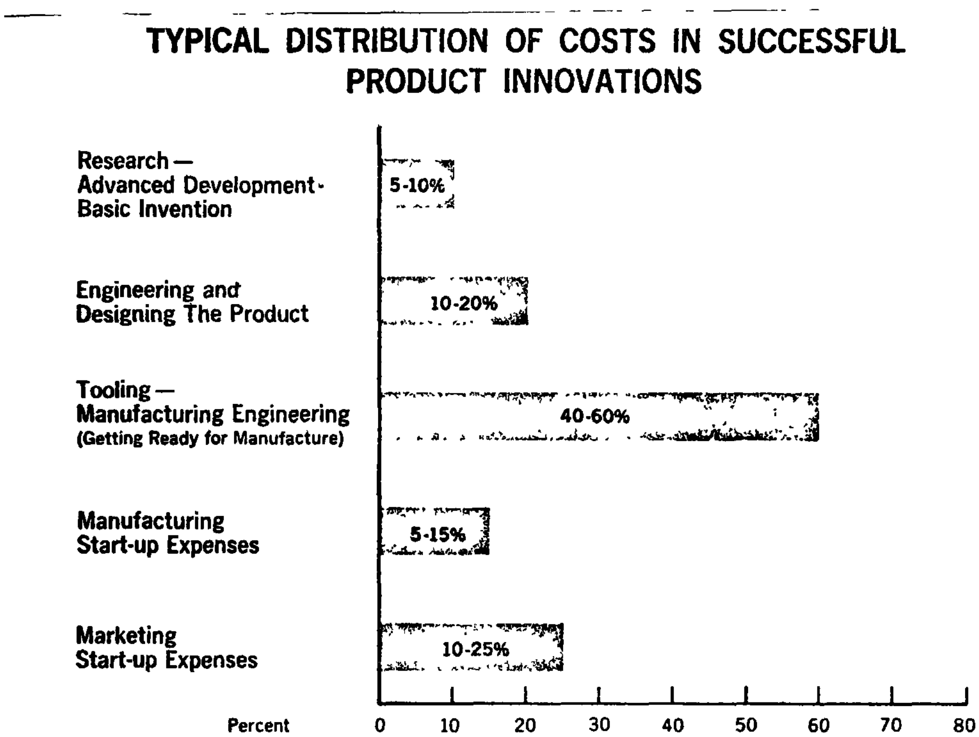
TABLE 31. LOGICAL SOURCE, ACTUAL SOURCE AND INITIAL SUPPORT OF NINE TECHNOLOGICAL INNOVATIONS.

Concept	"Logical" Concept Source	Actual Concept Source	Initial Commercial Support
Synthetic fiber (nylon)	Textile industry	Chemical industry	Du Pont
Diesel locomotive	Railroad equipment industry	Automobile industry	General Motors
Numerical control for machine tools	Machine-tool industry	Small control manufacturer	U.S. Air Force
Ball-point pen	Fountain pen manufacturer	Hungarian sculptor and chemist (Biro brothers)	Individual
Polaroid film	Photographic industry	Independent scientist (Dr. Land)	Independently financed
Color film	Photographic industry	Two musicians (Godowsky and Mannes)	Eastman Kodak
DDT insecticide	Insecticide or agricultural chemicals manufacturer	Synthetic dye manufacturer	Same as source
Computer	Business machine manufacturer	Universities	U.S. Government
Hydrofoil boats	Major shipbuilder or U.S. Navy	Inventor of the telephone	Italian businessman

Source: BRIGHT, J.R., "On Sources of Technological Innovation", Research, Development and Technological Innovation, Richard D. Irwin, Inc., Illinois, U.S.A., 1964, p. 380.

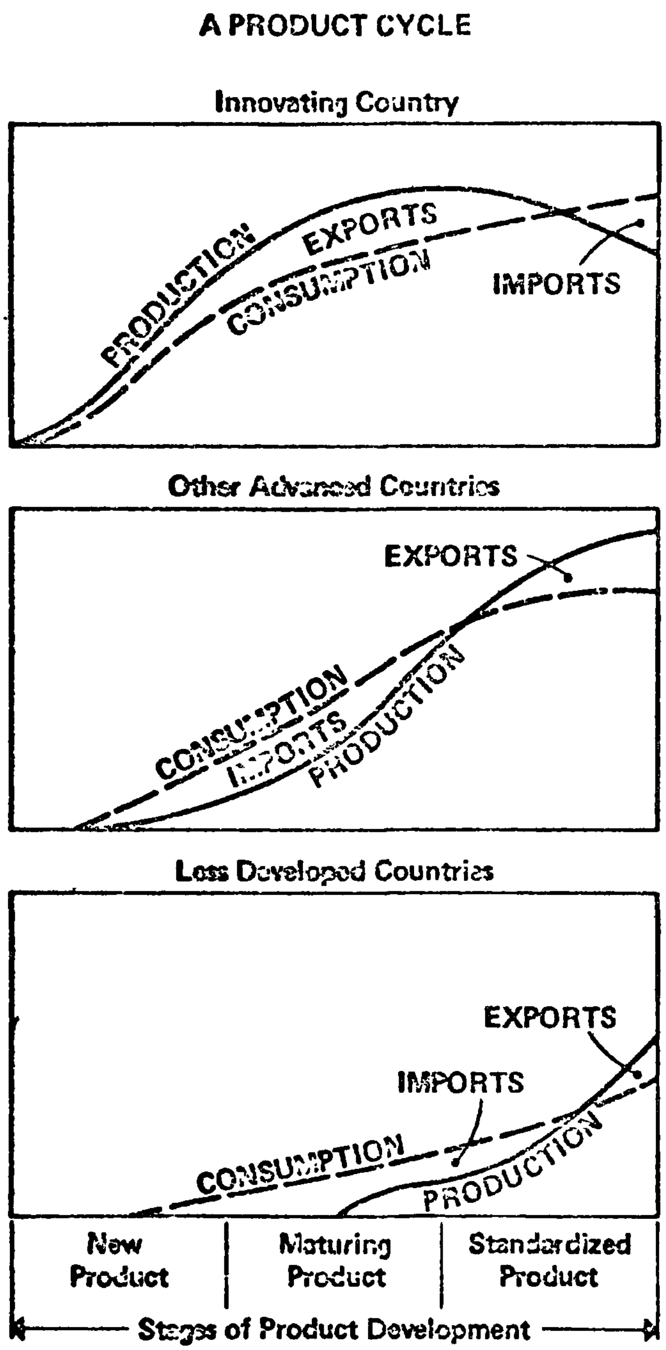
CHARTS

CHART I



Source: United States Department of Commerce, _Technological Innovation_, U.S. Government Printing Office, Washington, D.C., January, 1969, p. 9.

CHART II


A PRODUCT CYCLE
Innovating Country
PRODUCTION
EXPORTS
CONSUMPTION
IMPORTS
Other Advanced Countries
EXPORTS
CONSUMPTION
IMPORTS
PRODUCTION
Less Developed Countries
EXPORTS
IMPORTS
CONSUMPTION
PRODUCTION
New Product
Maturing Product
Standardized Product
Stages of Product Development

APPENDIX B

BIBLIOGRAPHY

a) BOOKS

BRIGHT, J.R., Research, Development and Technological Innovation, Richard D. Irwin, Inc., Homewood, Illinois, 1964.

BROOKS, H., The Government of Science, M.I.T. Press, Cambridge, Mass., and London, England, 1968.

CALDER, N., Technopolis, MacGibbon & Kee Ltd., Bristol, 1969.

CARTER, C.F., and WILLIAMS, B.R., Investment in Innovation, Oxford University Press, London, New York, Toronto, 1958.

DENISON, E., The Sources of Economic Growth in the United States; Committee for Economic Development, 1962.

FAUNCE, W.A., Problems of an Industrial Society, McGraw-Hill Book Company, New York, 1968.

FORBES, R.J., The Conquest of Nature, Frederick A. Praeger, Publishers, New York, 1968.

FROMM, Eric, Escape From Freedom, Holt, Rinehart & Winston Inc., New York, 1941.

GALBRAITH, J.K., The New Industrial State, A Signet Book, The New American Library, New York, 1967.

--- The Affluent Society, A Mentor Book, The New American Library, New York and Toronto, 1958.

JEWKES, J.D., SAWERS and R. STILLERMAN, The Sources of Invention, St. Martin's Press, Inc., New York, 1958.

KELLY, Frank, Prospects for Scientists and Engineers in Canada, Background Study for the Science Council of Canada, Special Study # 20, 1971.

LINDER, S.B., The Harried Leisure Class, Columbia University Press, New York and London, 1970.

MANSFIELD, E., The Economics of Technological Change, W.W. Norton & Co., Inc., New York, 1968.

--- Industrial Research and Technological Innovation, W.W. Norton & Co., Inc., New York, 1968.

McLUHAN, H.M., The Medium is the Message, Co-ordinated by J. Agel, Random House, New York, 1967.

MYERS, S., MARQUIS, D.G., Successful Industrial Innovations, A Study of Factors Underlying Innovation in Selected Firms for the National Science Foundation, U.S. Government Printing Office, Washington, D.C., 1969.

NELSON, R.R., PECK, M.J., KALACHEK, E., Technology, Economic Growth And Public Policy, The Brookings Institution, Washington, D.C., 1967.

NOLTINGK, B.E., The Art of Research, Elsevier Publishing Co., Amsterdam, 1965.

PACKARD, Vance, The Waste Makers, David McKay Co., Inc., New York, 1960.

REAGAN, M.D., Science and the Federal Patron; Oxford University Press, New York, 1969.

RIDKER, R.G., The Economic Costs of Air Pollution, Frederick A. Praeger (Publishers), New York, 1967.

SCHMOOKLER, J., Invention and Economic Growth, Cambridge, Mass., Harvard University Press, 1966.

SCHON, D.A., Technology and Change, A Delta Book, Dell Publishing Co., Inc., New York, 1967.

SHANKS, M., The Innovators: The Economics of Technology, A Penguin Book, Baltimore, 1967.

SOMERS, G.G., CUSHMAN, E.L., WEINBERG, N. (editors), Adjusting to Technological Change, Harper & Row Publishers, New York, Evanston, and London, 1963.

STRASSMANN, W.P., Technological Change and Economic Development, Ithaca, Cornell University Press, New York, 1968.

TAYLOR, C., and BARRON, F., Creativity, Progress and Potential, McGraw Hill, New York, 1964.

TYBOUT, R.A. (editor), Economics of Research and Development, A Publication of the Mershon Center for Education in National Security, Ohio State University Press, 1965.

United States Department of Commerce, Technological Innovation: Its Environment and Management, U.S. Government Printing Office, Washington, D.C., January, 1969 (p. 9).

VILLERS, Raymond and VILLERS, Rautenstrauch, Research and Development: Planning and Control, Financial Executives Research Foundation, Inc., New York, 1964.

WARNER, W.A., MORSE, D., COONEW, T.E. (editors), The Environment of Change, Columbia University Press, New York and London, 1965.

WILLIAMS, B.R., Technology, Investment and Growth, Chapman and Hall Ltd., London, 1967.

WILSON, A.H., Background to Invention, Background Study for the Science Council of Canada, Special Study No. 11, Queen's Printer for Canada, Ottawa, 1970.

--- Science, Technology and Innovation, prepared for the Economic Council of Canada, Special Study No. 8, Queen's Printer, Ottawa, May, 1968.

b) ARTICLES

AIGRAIN, P., "Some Factors Inhibiting Technological Innovation in France", The Process of Technological Innovation, National Academy of Sciences, Wash., D.C., 1969.

ALLEN, T.J., "The Differential Performance of Information Channels in the Transfer of Technology", Factors in the Transfer of Technology, edited by W.H. Gruber and D.G. Marquis, M.I.T. Press, Cambridge, Mass., and London, England, 1969.

ANDREWS, F.M., PELZ, D.C., "Freedom in Research", The R & D Game, edited by D. Allison, the M.I.T. Press, 1969.

BRIGHT, J.R., "Evaluating Signals of Technological Change", Harvard Business Review, Jan.-Feb., 1970.

CHARPIE, R.A., "Technological Innovation and International Economy", Technological Innovation and the Economy, edited by Maurice Goldsmith; Science of Science Foundation, London, 1970, pp. 1-12.

CARTER, C.F., "The Distribution of Scientific Effort", Criteria for Scientific Development, A Selection of Articles From Minerva, edited by E. Shils, the M.I.T. Press, 1968.

CASIMIR, H.B.C., "Basic Science as a Source of Innovation and Vice Versa", The Process of Technological Innovation, National Academy of Sciences, Washington, D.C., 1969.

COTTRELL, A.H., "Technological Thresholds", The Process of Technological Innovation, National Academy of Sciences, Washington, D.C., 1969.

DEMONTS, Roger, "Le rendement social de la recherche scientifique et technique", Recherche et activité économique, published under François Perroux by Armand Colin, Paris, 1969.

FISHER, H.W., "Innovation in a Large Company", The Process of Technological Innovation, National Academy of Sciences, Washington, D.C., 1969.

GOLDMAN, J.E., "Basic Research in Industry", The R & D Game, M.I.T. Press, 1969.

MENCHER, A.G., and BLAKE, S.P., "Two Strategies for R & D Managers", Science Journal, June, 1969.

PELZ, D.C., "Freedom in Research", The R & D Game, edited by D. Allison, the M.I.T. Press, 1969.

POLANYI, R., "The Republic of Science", Criteria for Scientific Development, a selection of articles from Minerva, edited by E. Shils, M.I.T. Press, 1968.

PRICE, D.J. de SOLLA, "The Structures of Publication in Science and Technology", Factors in the Transfer of Technology, edited by W.H. Gruber and D.G. Marquis, M.I.T. Press, Cambridge and London, 1969.

--- "The Scientific Foundation of Science Policy", Nature, Volume 206, London, 1965, pp. 233 to 238.

ROTTENBERG, S., "The Warrants for Basic Research", Criteria for Scientific Development, a Selection of Articles from Minerva, edited by E. Shils, the M.I.T. Press, 1968.

RUDD, E., "The Rate of Economic Growth, Technology and the Ph.D.", Minerva, Spring, 1968.

Scientific American, Science, Conflict and Society, W. H. Freeman and Company, San Francisco, 1969.

SELIGMAN, B.B., "On Work, Alienation and Leisure", The American Journal of Economics and Sociology, Vol. 24, No. 4, October, 1965.

TOULMIN, S., "The Complexity of Scientific Choice: A Stocktaking", Criteria for Scientific Development, a selection of Articles from Minerva, edited by E. Shils, the M.I.T. Press, 1968.

WEINBERG, A.W., "Criteria for Scientific Choice II: The Two Cultures", Criteria for Scientific Development, a selection of articles from Minerva; edited by E. Shils, the M.I.T. Press, 1968.

--- "Scientific Choice and Biomedical Science", Criteria for Scientific Development, a selection of articles from Minerva; edited by E. Shils, the M.I.T. Press, 1968.

WEINBERG, A.M., "Criteria for Scientific Choice", Criteria for Scientific Development, a selection of articles from Minerva; edited by E. Shils, the M.I.T. Press, 1968.

"What's the Use of a Ph.D.? The Industrial Point of View", a Report of a speech delivered by Dr. E. Hoggarth on the 9th of September at the Annual Meeting of the British Association for the Advancement of Science in Exter, Chemistry and Industry, September, 1969.

c) OTHERS

Conseil Economique du Canada, Rapport sur la propriété intellectuelle et industrielle, Information Canada, Ottawa, Janvier, 1971.

Dominion Bureau of Statistics, Industrial R & D Expenditures in Canada, 1957, 1959, 1961, 1963, 1965, 1967, Queen's Printer, Ottawa.

--- Federal Government Expenditures on Scientific Activities for the Fiscal Year 1958-59 and 1960-61, to 1967-1968, Queen's Printer, Ottawa.

--- Expenditures on Scientific Activities by Non-Profit Organizations, Queen's Printer, Ottawa, 1965.

Dominion Bureau of Statistics, National Income and Expenditures Accounts 1926-1968, Queen's Printer, Ottawa, 1969.

Economic Development Division, Technological Innovation in Canada, Department of Finance, Canada, September, 1970.

Education Support Branch, Federal Expenditures on Research in Academic Community, 1966-67, 1967-68, Department of the Secretary of State, Report No. 1, Queen's Printer, Ottawa, 1969.

KINZEL, A.B., Industrial Research - Why, How and What, Conference delivered on July 17, 1967.

LUKASIEWICZ, J., Complexity and Saturation in an Environment of High Technology, paper presented at the 34th Annual Meeting, ASEE, SE Section, Miami, Florida, U.S.A., April 17th, 1969.

Organization for Economic Cooperation and Development, Review of National Science Policy: Canada, Paris, 1969.

--- Fundamental Research and the Policies of Governments, Ministerial meeting on Science, Paris, 1966.

--- R & D in OECD Member Countries: Trends and Objectives, DAS/SPR/70.31, Paris, 17th of August, 1970.

--- The Conditions for Success in Technological Innovation, Committee for Science Policy, SP(70)1, Paris, 1970.

ORR, J., A Technological Strategy for Industrial Development, paper presented to the Seminar on "A Nation Plans its Engineering Research" at the Tripartite Chemical Engineering Conference in Montreal, September 23, 1968.

PRICE, D.J. de SOLLA, Measuring the Size of Science, conference delivered to the Israel Academy of Sciences and Humanities, February the 11th, 1969.

Proceedings of the Special Committee on Science Policy; the Senate, Queen's Printer, Ottawa, 1967 to 1969.

Report of the Senate Special Committee on Science Policy: A Science Policy for Canada, Volume I, A Critical Review: Past and Present, Queen's Printer, Ottawa, 1970.

Science Council of Canada, Towards a National Science Policy, Report No. 4, Queen's Printer, Ottawa, 1968.

--- Industrial Research and Development in Canada, presented at its meeting on March 17, 1967, by J.L. Orr, Industrial Research Adviser, Department of Industry, Ottawa, 1967.

--- Scientific and Technical Information in Canada, Part I, Special Study No. 8, Queen's Printer, Ottawa, 1969.

VISCAS, A.G., "Research and Development in the Farm Machinery Industry", Royal Commission on Farm Machinery, Study No. 7, Queen's Printer, Ottawa, 1969.

WALTERS, G. and HUDSON, K. (editors), Technology and Society, the first Bath Conference, 1965, Bath University Press, 1966.